DOCUMENT RESUME

ED 212 813 CE 031 231

AUTHOR Mugan, Don
TITLE North Dakota Industrial Arts Teachers Handbook. Energy/Power Curriculum Guide, Level I.
INSTITUTION Valley City State Coll., N. Dak.
SPONS AGENCY North Dakota State Board for Vocational Education, Bismarck. Research Coordinating Unit.
PUB DATE [Dec 80]
NOTE 249p.

EDRS PRICE MF01/PC10 Plus Postage.
DESCRIPTORS Careers; *Energy; Energy Conservation; Fuel Consumption; Fuels; *Industrial Arts; Job Skills; Nuclear Energy; *Occupational Information; *Power Technology; Safety; Secondary Education; Teaching Guides; *Trade and Industrial Education
IDENTIFIERS Energy Consumption; Energy Conversion; *North Dakota Energy and Power Curriculum Guide; Power Transmission

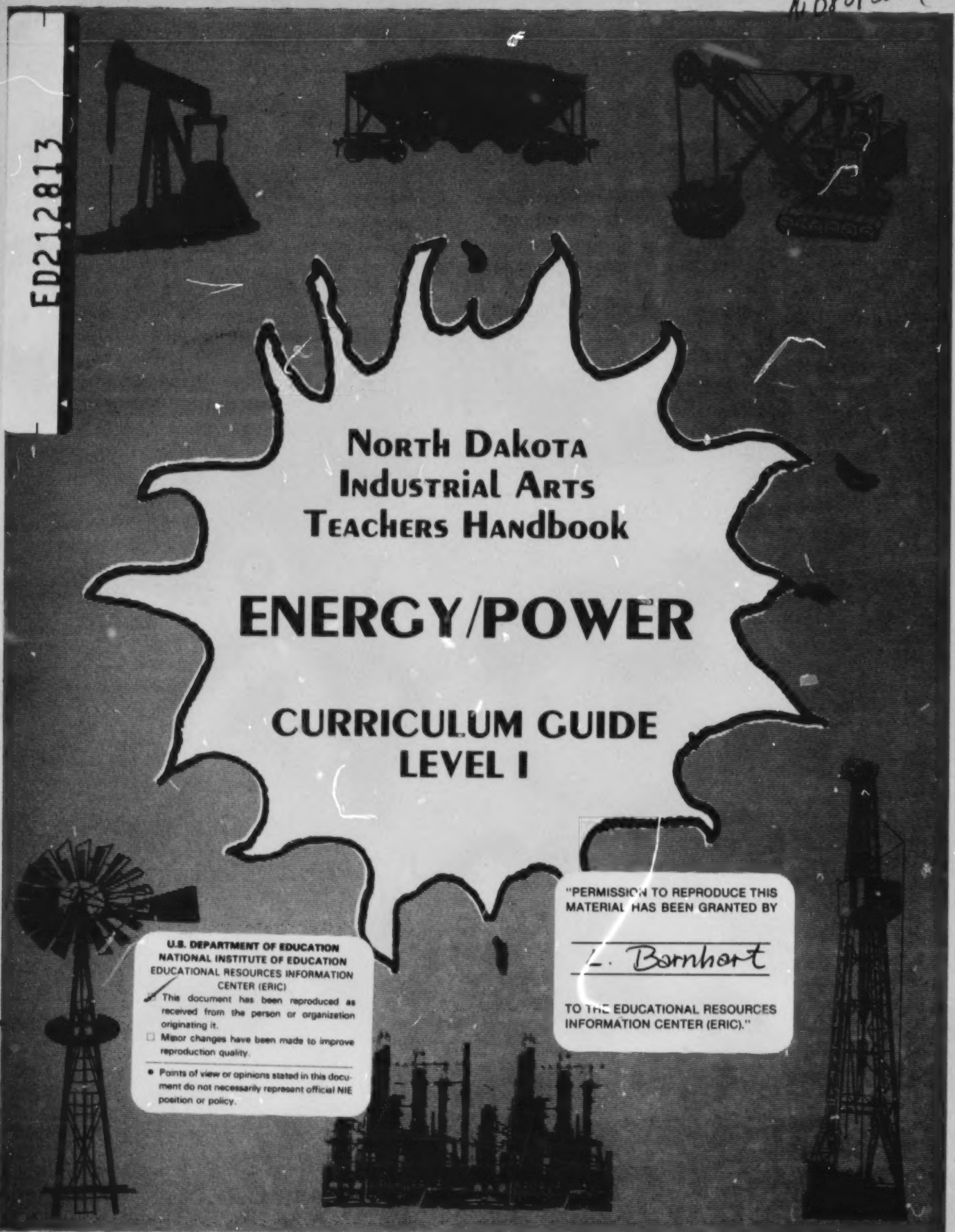
ABSTRACT

This handbook provides teachers with support material to more fully implement the North Dakota Energy and Power Curriculum Guide, Level I. It first presents the body of knowledge for Energy/Power Technology as taken from the curriculum guide. The guide is then addressed unit by unit, topic by topic. These seven units are covered: Energy/Power Introductory Concepts; Energy/Power Safety Concepts; Energy Forms and Sources; Energy Harnessing Systems and Newton's Law; Energy/Power Storage, Transmission, and Control; Energy/Power Utilization; and Energy/Power Career Opportunities. Lecture notes and at least one overhead original are provided for each unit and for each topic for the first five units which cover the technical and safety aspects of energy/power. Resource materials and suggestions for activities are presented for unit 6, and some activities are suggested for unit 7. Appendixes include a list of references, list of material and equipment suppliers, prefixes and English/metric conversions, and equipment construction notes. (YLB)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ND801 3304

ED212813



North Dakota Industrial Arts Teachers Handbook

ENERGY/POWER

CURRICULUM GUIDE LEVEL I

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☒ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

L. Bornhart

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

CE031231

THIS HANDBOOK PREPARED BY:

DR. DON MUGAN, PROF. & CHR.,
DIV. OF MATH SCIENCE & TECH.
VALLEY CITY STATE COLLEGE
VALLEY CITY, NORTH DAKOTA

UNDER A GRANT PROVIDED BY:

THE RESEARCH COORDINATING UNIT
NORTH DAKOTA STATE BOARD FOR
VOCATIONAL EDUCATION,
CARROL E. BURCHINAL, DIRECTOR

ENERGY/POWER TEACHERS HANDBOOK

FEATURES:

LECTURE NOTES
OVERHEAD TRANSPARANCY ORIGINALS
TEACHER DEMONSTRATIONS
STUDENT ACTIVITIES
APPENDICES
- A. REFERENCES
- B. LIST OF MATERIAL & EQUIPMENT SUPPLIERS
- C. PREFIXES AND ENGLISH/METRIC CONVERSIONS
- D. EQUIPMENT CONSTRUCTION NOTES

HOW TO USE THIS HANDBOOK:

THE PURPOSE OF THIS HANDBOOK IS TO ENCOURAGE THE IMPLEMENTATION OF A BROAD, INCLUSIVE AND EXCITING APPROACH TO THE STUDY OF ENERGY AND POWER, REGARDLESS OF BACKGROUND OF THE INSTRUCTOR OR LIMITATIONS OF FACILITY. TO THIS END, THE NORTH DAKOTA ENERGY AND POWER CURRICULUM GUIDE, LEVEL I, IS ADDRESSED UNIT BY UNIT, TOPIC BY TOPIC, SO THAT AT LEAST A VISUAL CAN BE PRESENTED AND A DISCUSSION PURSUED. THUS, NO MAJOR AREA WILL BE IGNORED FOR WANT OF SUITABLE EQUIPMENT.

LECTURE NOTES AND AT LEAST ONE OVERHEAD ORIGINAL ARE PROVIDED FOR EACH UNIT AND EACH TOPIC FOR THE FIRST FIVE UNITS WHICH COVER THE TECHNICAL AND SAFETY ASPECTS OF ENERGY/POWER. RESOURCE MATERIAL AND SUGGESTIONS FOR ACTIVITIES ARE PROVIDED FOR UNIT SIX, UTILIZATION, AND SOME SUGGESTIONS FOR ACTIVITIES ARE ALSO PROVIDED FOR UNIT SEVEN, CAREERS.

AN UNFORTUNATE HUMAN TENDENCY IS PROCRASTINATION AND IT USUALLY PREVENTS US FROM PREPARING FOR A COURSE UNTIL IT IS UPON US. ALSO UNFORTUNATE IS THE FACT THAT WHILE MANY MATERIALS ARE AVAILABLE LOCALLY, MANY ARE NOT, SO A GOOD FIRST STEP IN PREPARING FOR THIS COURSE IS TO ASK A SECRETARY TO ORDER COPIES OF ALL SUPPLY CATALOGUES LISTED IN THE APPENDIX AFTER READING THIS PAGE. IT HAS BEEN SAID THAT NOTHING IS NEW UNDER THE SUN. WHILE THIS MAY BE A DEBATABLE STATEMENT, IT UNDERSCORES THE FACT THAT IT IS DIFFICULT TO BE CREATIVE AND MOVE FORWARD WITHOUT KNOWING WHAT EXISTS UNDER THE SUN. A SECOND STEP IN PREPARING FOR THIS COURSE WOULD BE THE ORDERING OF ALL RESOURCES LISTED IN THE APPENDIX, ESPECIALLY THE FREE GOVERNMENT MATERIALS. AFTER ASSEMBLING CATALOGUES AND RESOURCE MATERIALS REVIEW THIS HANDBOOK, THE CURRICULUM GUIDE, AND SEVERAL RESOURCES AND MAKE A LIST OF ACTIVITIES THAT IS APPROPRIATE FOR YOUR SITUATION SO THAT MATERIALS CAN BE ORDERED.

FINALLY, IT IS IMPORTANT THAT THE CURRICULUM OUTLINE BE FOLLOWED CONSISTANTLY, ANYTHING LESS IS INADEQUATE SINCE THE PACE OF TECHNOLOGICAL CHANGE MAKES EVEN THE MOST AMBITIOUS TEACHING EFFORT MARGINAL. IT IS WITHIN REACH TO INCLUDE MOST SUGGESTIONS PRESENTED IN THIS GUIDE, AS NO SOPHISTICATED, EXPENSIVE TRAINERS ARE REQUIRED. MOST ACTIVITIES AND DEMONSTRATIONS CAN BE ACCOMPLISHED FOR UNDER $25.00, SOME FOR CONSIDERABLY LESS.

ENERGY/POWER TECHNOLOGY

BODY OF KNOWLEDGE
(TAKEN FROM ENERGY/POWER LEVEL I CURRICULUM GUIDE)

1.00 ENERGY/POWER INTRODUCTORY CONCEPTS

- 1.10 THE ENERGY TREE (SUN AS ORIGIN)
  - 1.11 LIGHT → HEAT →
  - 1.12 CHEMICAL REACTION → VEGETATION
  - 1.13 CHEMICAL REACTION → FOSSIL FUELS → ETC.
  - 1.14 CONSERVATION AND RESEARCH
- 1.20 TWO BASIC ENERGY TYPES
  - 1.21 KINETIC
  - 1.22 POTENTIAL
- 1.30 HISTORICAL HARNESSING AND ENERGY USES
  - 1.31 MUSCLE POWER
  - 1.32 WATER AND WIND
  - 1.33 HEAT AND STEAM
  - 1.34 GRAVITY
- 1.40 BASIC MEASURANDS, BASIC AND DERIVED UNITS, AND INTERRELATIONSHIPS
  - 1.41 ENERGY (JOULE)
  - 1.42 POWER (WATT)
  - 1.43 FORCE (NEWTON)
  - 1.44 TORQUE (NEWTON METER)
  - 1.45 PRESSURE (PASCAL)
  - 1.46 THERMAL ENERGY (CALORIE)
  - 1.47 MASS, LENGTH, TIME, ETC.

2.00 ENERGY/POWER SAFETY CONCEPTS

- 2.10 HAZARDS
  - 2.11 CHEMICAL
  - 2.12 ELECTRICAL
  - 2.13 MECHANICAL
  - 2.14 RADIATION (LIGHT AND NUCLEAR)
  - 2.15 THERMAL
- 2.20 PREVENTIVE MEASURES
  - 2.21 ATTITUDES
  - 2.22 KNOWLEDGE OF CORRECT USAGE
  - 2.23 EQUIPMENT
  - 2.24 FACILITIES

2.30 PROTECTIVE MEASURES

2.31 APPARREL
2.32 CONTAINERING METHODS
2.33 SHIELDING (EYES, FACE, INSULATIVE, ETC.)
2.34 GROUNDING AND/OR APPROPRIATE MOUNTING

2.40 CORRECTIVE MEASURERS

2.41 EXTINGUISHERS
2.42 INHIBITORS
2.43 NEUTRALIZERS

3.00 ENERGY FORMS AND SOURCES

3.10 CHEMICAL

3.11 FOSSIL FUELS
3.111 COAL
3.112 OIL
3.113 NATURAL GAS

3.12 BIOFUELS
3.121 BIOMASS (PLANT MATTER)
3.122 AGRICULTURE
3.123 AQUACULTURE
3.124 METHANE
3.125 ALCOHOL
3.126 WOOD

3.20 ELECTRICAL

3.21 ELECTROSTATIC
3.211 FRICTION
3.212 LIGHTNING

3.22 MAGNETIC

3.30 LIGHT

3.31 SOLAR
3.311 HELIOCHEMICAL (PHOTOSYNTHESIS)
3.312 HELIOELECTRICAL (SOLAR CELLS, ETC.)
3.313 HELIOTHERMAL (SOLAR COLLECTORS)

3.32 RADIOACTIVE

3.40 MECHANICAL

3.41 WIND
3.411 CLIMATE AND ATMOSPHERIC CONDITIONS
3.412 WIND-DRIVEN GENERATORS AND ALTERNATORS
3.413 BLADES AND HUBS

3.42 WATER
- 3.421 TIDAL
- 3.422 WAVES
- 3.423 MEASURING AVAILABLE WATER POWER
- 3.424 DAMS
- 3.435 CHANNEL, SLUICES AND PIPES

3.43 GRAVITATIONAL

3.50 NUCLEAR

3.51 ATOMIC, RADIOACTIVE
- 3.511 ATOMIC THEORY
- 3.512 CHEMICAL ENERGY
- 3.513 ELECTRONS AND ENERGY
- 3.514 NUCLEAR FUELS
- 3.515 REACTOR PRINCIPLE AND POWER

3.52 SOLAR
- 3.521 ENERGY OF SUN
- 3.522 ENERGY OF RADIOACTIVITY
- 3.523 NUCLEAR FISSION
- 3.524 NUCLEAR FUSION

3.60 THERMAL

- 3.61 GEOTHERMAL
- 3.62 SOLAR
- 3.63 CRYOGENIC (SUPER COLD)

4.00 ENERGY HARNESSING SYSTEMS AND NEWTON'S LAWS

4.10 NONCONVERSION, DIRECT CONVERSION, AND INDIRECT CONVERSIONS

4.11 LAW OF CONSERVATION OF ENERGY

4.20 CHEMICAL ENERGY INPUT

- 4.21 FUEL CELL
- 4.22 BATTERIES
- 4.23 FUSION
- 4.24 FISSION
- 4.25 SUN
- 4.26 CHEMICAL HEATERS
- 4.27 INTERNAL COMBUSTION ENGINES
  - 4.271 ROCKET
  - 4.272 JET
  - 4.273 TURBOJET
  - 4.274 FAN-JET
  - 4.275 TURBO-PROP
  - 4.276 DIESEL
  - 4.277 GAS AND GAS TURBINES

4.28 EXTERNAL COMBUSTION ENGINE
- 4.281 STEAM (PISTON AND TURBINE)
- 4.282 STIRLING

4.29 CHEMICAL EXPLOSIVES
- 4.291 BLACK POWDER
- 4.292 DETONATING EXPLOSIVES

4.30 MECHANICAL ENERGY INPUT

4.31 PNEUMATIC DRIVEN
- 4.311 WIND TURBINE
  - 4.3111 AIR MOTOR
  - 4.3112 WINDMILL
- 4.312 SAIL AND SAILBOATS
- 4.313 PISTON DEVICES
  - 4.3131 JACK HAMMER

4.32 HYDRAULIC DRIVEN
- 4.321 WATER TURBINE
- 4.322 HYDRAULIC MOTOR
- 4.323 PISTON DEVICES
  - 4.3231 SHOCK ABSORBERS OR ADJUSTABLE SCREEN DOOR CLOSERS
  - 4.3232 HYDRAULIC RAM

4.33 PIEZOELECTRIC EFFECT

4.34 ELECTRIC GENERATOR AND ALTERNATORS

4.40 ELECTRICAL ENERGY INPUT

- 4.41 MOTORS
- 4.42 SOLENOIDS
- 4.43 SPEAKERS
- 4.44 NICHROME WIRE HEATING ELEMENT
- 4.45 CRYSTALS
- 4.46 RADIO
- 4.47 TELEVISION
- 4.48 HEATERS
- 4.49 LIGHTS
- 4.410 REFRIGERATOR SYSTEMS
- 4.411 LASER
- 4.412 LIGHT EMITTING DIODE (LED)
- 4.413 VACUUM TUBES
- 4.414 SEMICONDUCTORS
- 4.415 MAGNETOHYDRODYNAMIC GENERATOR
- 4.416 MICROWAVE OVENS
- 4.417 ETC.

4.50 NUCLEAR ENERGY INPUT

- 4.51 NUCLEAR REACTORS
- 4.52 RADIOACTIVE ISOTOPES
- 4.53 X-RAYS
- 4.54 NUCLEAR BATTERY

4.60 THERMAL ENERGY INPUT

- 4.61 THERMOSTAT
- 4.62 THERMOCOUPLE (THERMOELECTRIC GENERATOR)
- 4.63 THERMOINIC DEVICE
- 4.64 BOILING (WATER/STEAM)
- 4.65 HEAT RADIATION
- 4.66 THERMOPHOTOVOLTAIC CONVERTER (TPV) (SOLAR DWELLING)

4.70 LIGHT ENERGY INPUT

- 4.71 PHOTOVOLTAIC CELL (SOLAR CELL)
- 4.72 PHOTOCONDUCTIVE CELL
- 4.73 PHOTOSYNTHESIS (SOLAR DWELLING)

5.00 ENERGY/POWER STORAGE, TRANSMISSION AND CONTROL

5.10 STORAGE OF ENERGY

5.11 MOMENTARY

- 5.111 IGNITION COIL
- 5.112 CAPACITOR
- 5.113 METAL SPRING
- 5.114 ETC.

5.12 TEMPORARY

- 5.121 BATTERY
- 5.122 DAM
- 5.123 HEAT STORAGE TANK
- 5.124 SHIELDED NUCLEAR STORAGE DEVICE
- 5.125 ETC.

5.20 MEDIA OF TRANSMISSION

5.21 ELECTRICAL ENERGY

5.211 GAS OR VACUUM MEDIA

- 5.2111 ELECTROMAGNETIC WAVES
- 5.2112 LAMPS
- 5.2113 TUBES
- 5.2114 ETC.

5.212 SOLID MEDIA

- 5.2121 CONDUCTORS, WIRES, ETC.
- 5.2122 SEMICONDUCTORS, SOLID STATE, ETC.

5.213 LIQUID MEDIA

- 5.2131 ELECTROPLATING
- 5.2132 IONIZATION
- 5.2133 ETC.

5.22 LIGHT ENERGY
- 5.221 GAS OR VACUUM MEDIA
  - 5.2211 ELECTROMAGNETIC RADIATION
  - 5.2212 ETC.
- 5.222 SOLID MEDIA
  - 5.2221 TRANSPARENT MATERIALS (GLASS TRANSMISSION CABLE)
  - 5.2222 TRANSLUCENT MATERIALS
- 5.223 LIQUID (CRYSTAL DISPLAY DEVICES)

5.23 THERMAL ENERGY
- 5.231 GAS MEDIA
  - 5.2311 CONDUCTION, CONVECTION, AND RADIATION
- 5.232 SOLID
  - 5.2321 CONDUCTION
- 5.233 LIQUID
  - 5.2331 CONDUCTION AND CONVECTION

5.24 MECHANICAL ENERGY
- 5.241 GAS MEDIA
  - 5.2411 WIND TURBINE (WINDMILL)
  - 5.2412 SAILS
  - 5.2413 PNEUMATIC DRIVEN AND PISTON DEVICES
- 5.242 SOLID MEDIA
  - 5.2421 BELTS AND DRIVE CHAINS
  - 5.2422 CAMS
  - 5.2423 LEVERS
  - 5.2424 SCREWS
  - 5.2425 WHEEL AND AXLE
  - 5.2426 COUPLINGS
  - 5.2427 LINKAGES
  - 5.2428 EXPLOSIVES
- 5.243 LIQUID MEDIA
  - 5.2431 WATER TURBINE
  - 5.2432 HYDRAULIC DRIVEN AND PISTON DEVICES

5.25 CHEMICAL ENERGY
- 5.251 GAS MEDIA (FUEL CELL)
- 5.252 SOLID MEDIA (DRY CELL)
- 5.253 LIQUID MEDIA (WET CELL)

5.26 NUCLEAR ENERGY
- 5.261 GAS MEDIA (REACTOR PRINCIPLE)
- 5.262 SOLID MEDIA (OBLATION PRINCIPLE)
- 5.263 LIQUID MEDIA

5.30 CONTROL SYSTEMS

5.31 SENSING AND SENSORS (FOR CONTROL PURPOSES)

5.311 SENSED INFORMATION
5.3111 QUANTITATIVE SENSING
5.3112 QUALITATIVE SENSING
5.312 CHEMICAL SENSORS
5.3121 PH METER (SENSES ION CONCENTRATION)
5.3122 GALVANOMETER (SENSES POTENTIAL BETWEEN METALS IN AN ELECTROLYE SOLUTION)
5.3123 SMOKE DETECTORS
5.313 ELECTRICAL SENSORS
5.3131 RELAY (SENSES QUANTITY OF CURRENT)
5.3132 GALVANOMETER (SENSES MINUTE VOLTAGES)
5.3133 AMMETER
5.3134 OSCILLOSCOPE
5.314 LIGHT SENSORS
5.3141 PHOTOVOLTAIC (SOLAR) CELL
5.3142 PHOTOCONDUCTIVE CELL
5.315 MECHANICAL SENSORS
5.3151 PLUMB BOB
5.3152 PROVING RING
5.3153 STRAIN GAUGE (POP-OFF VALVE, MANOMETER, ETC.)
5.316 NUCLEAR SENSORS
5.3161 GEIGER COUNTER
5.317 THERMAL SENSORS
5.3171 THERMOSTAT
5.3172 THERMOCOUPLE

6.00 ENERGY/POWER UTILIZATION (EMPHASIS ON SAFE, EFFICIENT AND CONSERVATIVE USE IN ALL OF THE BELOW INDICATED APPLICATIONS).

6.10 RESIDENTIAL

6.11 LIGHT ENERGY
6.111 ILLUMINATION
6.112 SENSING (ALARMS, ETC.)
6.113 VIEWING (TV)
6.114 ULTRAVIOLET LAMPS

6.12 THERMAL ENERGY
6.121 HEATING AND COOLING
6.122 LIQUID AND FOOD REFRIGERATION AND HEATING
6.123 HEAT LAMPS

6.13 MECHANICAL ENERGY
6.131 MOTOR-DRIVEN APPLIANCES AND TOOLS
6.132 ENGINE-DRIVEN DEVICES
6.133 DOOR ACTIVATION MECHANISMS

6.14 NUCLEAR ENERGY
6.141 GASEOUS DETECTION

6.20 COMMERCIAL (SERVICES AND PRODUCTS ARE DISTRIBUTED)

6.21 LIGHT ENERGY
- 6.211 ILLUMINATION
- 6.212 SENSING (ALARMS, ETC.)
- 6.213 IMAGE DEVELOPMENT AND VIEWING (FILM DEVELOPMENT AND TV)

6.22 THERMAL ENERGY
- 6.221 HEATING AND COOLING
- 6.222 SUBSTANCE HEATING (OVENS, TORCHES, ETC.)
- 6.223 DRYING

6.23 MECHANICAL ENERGY
- 6.231 PNEUMATIC DRIVEN (MOTOR, PISTON AND TURBINE DEVICES)
- 6.232 HYDRAULIC DRIVEN (MOTOR, PISTON AND TURBINE DEVICES)
- 6.233 ELECTRIC DRIVEN (SOLENOIDS, MOTORS, ETS.)

6.24 NUCLEAR ENERGY
- 6.241 MEDICAL AND FOOD TREATMENT
- 6.242 GASEOUS DETECTION

6.30 INDUSTRIAL (PRODUCTS ARE PRODUCED)

6.31 LIGHT ENERGY
- 6.311 ILLUMINATION
- 6.312 SENSING

6.32 THERMAL ENERGY
- 6.321 CLIMATE CONTROL
- 6.322 SUBSTANCE HEATING

6.33 MECHANICAL ENERGY
- 6.331 PNEUMATIC DRIVEN
- 6.332 HYDRAULIC DRIVEN
- 6.333 ELECTRIC DRIVEN

6.34 NUCLEAR ENERGY
- 6.341 INSPECTION
- 6.342 ELECTRICAL PRODUCTION

6.40 TRANSPORTATION

6.41 AIR OR SPACE
- 6.411 INTERNAL COMBUSTION (PISTON, ROCKET, TURBINE)

6.42 SURFACE
- 6.421 INTERNAL COMBUSTION ENGINES
- 6.422 EXTERNAL COMBUSTION ENGINES
- 6.423 ELECTRICAL
- 6.424 GRAVITATIONAL
- 6.425 MUSCLE

6.43 WATER
- 6.431 INTERNAL COMBUSTION ENGINES
- 6.432 NUCLEAR
- 6.433 MUSCLE
- 6.434 ELECTRICAL
- 6.435 WIND ROTOR

7.00 ENERGY/POWER CAREER OPPORTUNITIES

(EMPHASIS ON DUTIES, RESPONSIBILITIES, MAIN JOB REQUIREMENTS AND TRAINING PROGRAMS--AND INCLUDING THE CONCEPT OF INTERCATEGORY ASSIGNMENTS, I.E., THE TECHNICIAN CAN CONTRIBUTE SKILLS IN THE AREA OF SERVICING, RESEARCH AND DEVELOPMENT, MAINTENANCE, ETC.)

7.10 PROFESSIONAL

- 7.11 ENGINEER/DESIGNER
- 7.12 INVENTOR
- 7.13 RESEARCHERS/SCIENTISTS
- 7.14 EDUCATORS
- 7.15 EXECUTIVES/MANAGERS

7.20 TECHNICAL

- 7.21 QUALITY/PRODUCTION SUPERVISOR
- 7.22 ENGINEERING ASSISTANT
- 7.23 SUPERINTENDENT/FOREMAN
- 7.24 DRAFTING/DESIGN PERSONNEL
- 7.25 EXPERIMENTAL PERSONNEL

7.30 SKILLED

- 7.31 ELECTRICIANS
- 7.32 ASSEMBLERS
- 7.33 MACHINISTS

7.40 SEMI-SKILLED

- 7.41 ON-THE-JOB TRAINEES
- 7.42 SELF-IMPROVED WORKERS

7.50 UNSKILLED

- 7.51 HELPERS
- 7.52 LABORERS
- 7.53 ATTENDANTS

unit 1
energy/power
introductory concepts

LECTURE NOTES

CERTAINLY, IT WOULD SEEM LOGICAL THAT THE FIRST TASK OF A COURSE IN ENERGY AND POWER WOULD BE TO CLARIFY THE MEANING OF SUCH WIDELY USED AND MUSUSED WORDS AS ENERGY AND POWER. THESE TWO WORDS, TOGETHER WITH ASSOCIATED CONCEPTS, FORM THE HEART OF THE COURSE. AND, WITHOUT A CLEAR UNDERSTANDING OF THESE TWO TERMS AND CONCEPTS, THE LECTURES, DEMONSTRATIONS AND EXPERIMENTS WOULD BE,AT BEST, ENTERTAINING. THE MAJOR OBJECTIVE OF THE FIRST UNIT IS TO SUPPLEMENT THE CURRICULUM GUIDE BY PROVIDING THIS NECESSARY FOUNDATION.

LABORATORY EXPERIMENTS WILL INVOLVE STUDENT ENERGY AND STUDENT GENERATED POWER TO MAXIMIZE INVOLVEMENT AND PERSONALIZE THE MEANING OF KEY POINTS.

CURRICULUM GUIDE OUTLINE

1.10 THE ENERGY TREE (SUN AS ORIGIN)

- 1.11 LIGHT ⟶ HEAT
- 1.12 CHEMICAL REACTION ⟶ VEGETATION
- 1.13 CHEMICAL REACTION ⟶ FOSSIL FUEL ⟶ ETC.
- 1.14 CONSERVATION AND RESEARCH

THE ABOVE TOPIC AND SUBTOPICS ARE ADDRESSED IN VISUAL #1. THE VISUAL ATTEMPTS TO COMMUNICATE THE CONCEPT THAT MUCH OF THE ENERGY WE USE TODAY ORIGINALLY CAME FROM THE SUN (MILLIONS OF YEARS AGO) AND RESULTED FROM AN ATOMIC REACTION WHEREBY HYDROGEN ATOMS FUSED TOGETHER TO FORM HELIUM AND IN THE PROCESS RELEASED TREMENDOUS AMOUNTS OF ENERGY WHICH WAS RADIATED TO EARTH WHERE IT WAS CAPTURED BY PLANTS (VISUAL #2) AND STORED IN CHEMICAL FORM.

LATER, MUCH OF THIS PLANT MATTER WAS BURIED BY NATURAL FORCES WHERE THE HEAT AND PRESSURE CAUSED A SECOND CHEMICAL REACTION AND TRANSFORMED THE PLANT MATERIAL INTO FOSSIL FUELS SUCH AS COAL, A FORM OF STORED CHEMICAL ENERGY.

SUBTOPIC 1.14, CONSERVATION AND RESEARCH, PROVIDES A TOPIC FOR DISCUSSION SINCE FOSSIL FUELS FORMED MILLIONS OF YEARS AGO WILL EVENTUALLY RUN OUT, AND CONSERVATION AND RESEARCH WILL PROVIDE THE ONLY ANSWERS FOR OUR CONTINUED ENERGY NEEDS.

AT THIS POINT, IT IS STRONGLY RECOMMENDED THAT ONE ORDER A TREMENDOUS SERIES OF FREE MATERIAL PREPARED BY THE NATIONAL SCIENCE TEACHERS ASSOCIATION. THIS SOURCE IS EXTREMELY VALUABLE FOR DISCUSSION PURPOSES FOR THE ABOVE TOPICS AND MANY TOPICS TO FOLLOW. SEE APPENDIX FOR ORDERING INFORMATION. ALSO, MANY OTHER FREE GOVERNMENT PUBLICATIONS ARE LISTED ALONG WITH ADDRESSES.

1

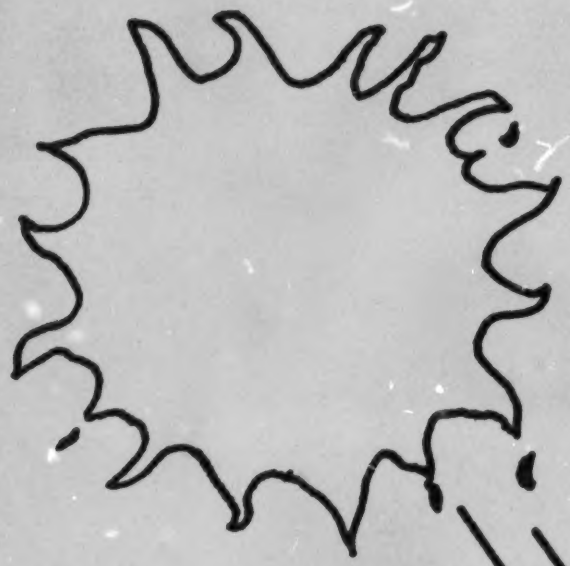
VISUAL #

SUN

NUCLEAR REACTION

HYDROGEN FUSION =

HELIUM + ENERGY



RADIANT ENERGY

EARTH

CHEMICAL REACTION

ENERGY +

WATER + MINERALS

= PLANT MATTER =

CHEMICAL ENERGY

HOW COAL WAS FORMED

CREDIT: NATIONAL SCIENCE TEACHERS ASSOC.

1-3

UNIT # 1 TOPIC 1 - THE ENERGY TREE

VISUAL # 2

LECTURE NOTES

CURRICULUM GUIDE OUTLINE

1.20 TWO BASIC ENERGY TYPES

1.21 KINETIC
1.22 POTENTIAL

BEFORE DISCUSSING THE TWO BASIC TYPES OF ENERGY, THE CONCEPT OF ENERGY SHOULD BE DEFINED MUCH MORE PRECISELY THAN FOUND IN THE COMMON USAGE.

VISUAL #3 DEFINES ENERGY AS THE ABILITY TO DO WORK. WORK IS DEFINED AS: WORK IS DONE WHEN A FORCE IS EXERTED AND MOVEMENT RESULTS. THE MATHEMATICAL RELATIONSHIP IS: WORK = FORCE X DISTANCE.

VISUAL #4 DISTINQUISHES BETWEEN TWO SIMILAR SITUATIONS. EXAMPLE #1 SHOWS A SITUATION WHERE WORK IS NOT ACCOMPLISHED AND EXAMPLE #2 SHOWS A SITUATION WHERE WORK IS ACCOMPLISHED.

WHY IS THERE NO WORK DONE IN EXAMPLE #1? BECAUSE ANY SOLID, LIQUID OR GAS CAN EXERT A FORCE WITHOUT MOVEMENT. A SECOND EXAMPLE COULD BE A TABLE WHICH EXERTS A FORCE UPWARD AGAINST GRAVITY. IF IT DID NOT, THEN THE TABLE WOULD COLLAPSE. YET WITHOUT MOVEMENT THE TABLE COULD NOT BE CLASSIFIED AS A WORK PRODUCING DEVICE. A THIRD EXAMPLE IS THAT OF TRACTOR AND IMPLEMENT STUCK IN MUD. WHILE THE TRACTOR IS EXERTING A PULLING FORCE IT HAS NOT ACCOMPLISHED A USEFUL WORK.

MOVING ON, VISUALS #5 AND #6 SHOW THAT THERE ARE TWO TYPES OF ENERGY, POTENTIAL AND KINETIC. IN VISUAL #5 POTENTIAL ENERGY IS DEFINED AS ENERGY IN STORAGE. SEVERAL WAYS THAT ENERGY CAN BE STORED ARE: IN A SPRING, A ROCK ON A HILL, WATER ABOVE A DAM, COMPRESSED AIR IN A TIRE, ETC.

IN VISUAL #6 KINETIC ENERGY IS DEFINED AS ENERGY IN MOTION. SEVERAL TYPES OF KINETIC ENERGY ARE ILLUSTRATED INCLUDING: WIND, WAVES, MUSCLE, GRAVITY, RIVERS AND VEHICLES.

AT THIS POINT STUDENTS MIGHT LIST MANY MORE EXAMPLES OF KINETIC ENERGY. IN SUMMARY, ENERGY IS THE ABILITY TO DO WORK, WORK RESULTS WHEN A FORCE IS EXERTED THROUGH A DISTANCE, ENERGY IN STORAGE IS CALLED POTENTIAL ENERGY, AND ENERGY IN MOTION IS CALLED KINETIC ENERGY.

IT SHOULD BE OBVIOUS THAT POTENTIAL ENERGY AND KINETIC ENERGY, WHILE DIFFERENT, ARE VERY CLOSELY RELATED AND IN THE SAME WAY ARE VERY CLOSELY RELATED TO WORK.

VISUAL # 3

WHAT IS ENERGY?

ENERGY IS

THE ABILITY TO DO WORK

WHAT THEN IS WORK?

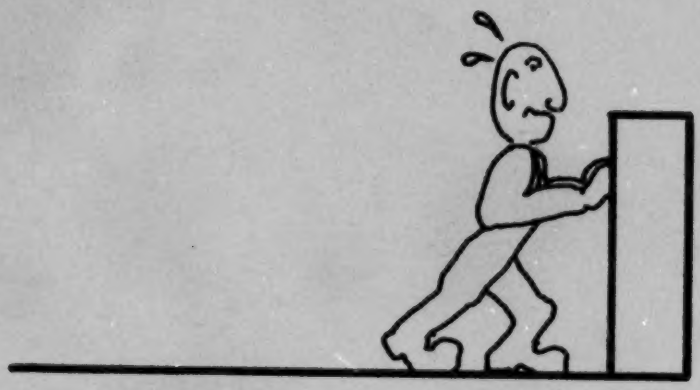
SIMPLY STATED

WORK IS DONE WHEN A FORCE IS EXERTED AND MOVEMENT RESULTS

STATED ANOTHER WAY:

WORK = FORCE X DISTANCE

EXAMPLE #1:



SOLID WALL

FORCE EXERTED, NO MOVEMENT, NO WORK DONE

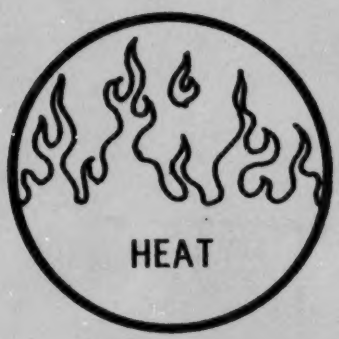
EXAMPLE #2:

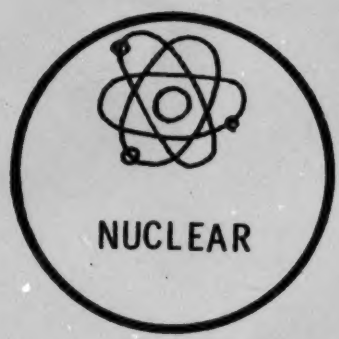
FORCE EXERTED, MOVEMENT RESULTS, WORK IS DONE

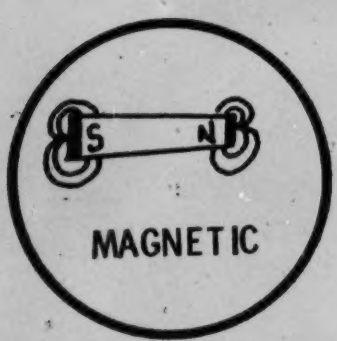
5

VISUAL #

POTENTIAL ENERGY IS ENERGY IN STORAGE. ENERGY CAN BE STORED MANY WAYS. NO MATTER HOW IT IS STORED IT IS ALWAYS CALLED POTENTIAL ENERGY.







VISUAL # 6

KINETIC ENERGY

ENERGY THAT RESULTS FROM MOTION IS CALLED KINETIC ENERGY.

23

TEACHER DEMONSTRATION

FOR EXAMPLE, WE COULD SAY THE CAR'S BATTERY HAS ENOUGH ENERGY TO START (POTENTIAL) THE ENGINE. OR, WE COULD SAY THAT THE CAR'S BATTERY IS STARTING (KINETIC) THE ENGINE. FURTHER, WE COULD SAY THAT A CERTAIN AMOUNT OF FORCE HAD TO BE APPLIED TO THE FLYWHEEL, AND THE FLYWHEEL HAD TO MOVE A CERTAIN DISTANCE TO GET THE CAR STARTED.

IN ALL THREE CASES DISCUSSED ABOVE, WE ARE TALKING ABOUT THE SAME AMOUNT OF ENERGY OR WORK. THUS, ANY UNITS WE MIGHT ATTACH TO ENERGY OR WORK IN FUTURE DISCUSSIONS ARE ONE AND THE SAME.

A SIMPLE DEMONSTRATION WITH OPPORTUNITY FOR STUDENT INVOLVEMENT FOLLOWS WHICH WILL CLARIFY THESE CONCEPTS.

OBJECTIVE: TO ILLUSTRATE THE RELATIONSHIP BETWEEN POTENTIAL ENERGY, KINETIC ENERGY AND WORK.

MATERIALS REQUIRED:
METER STICK
SUPER BALL
SILLY PUTTY
MISCELLANEOUS RUBBER BALLS.

PROCEDURE:

1. PLACE SEVERAL RUBBER BALLS ON A HARD SURFACED FLOOR.

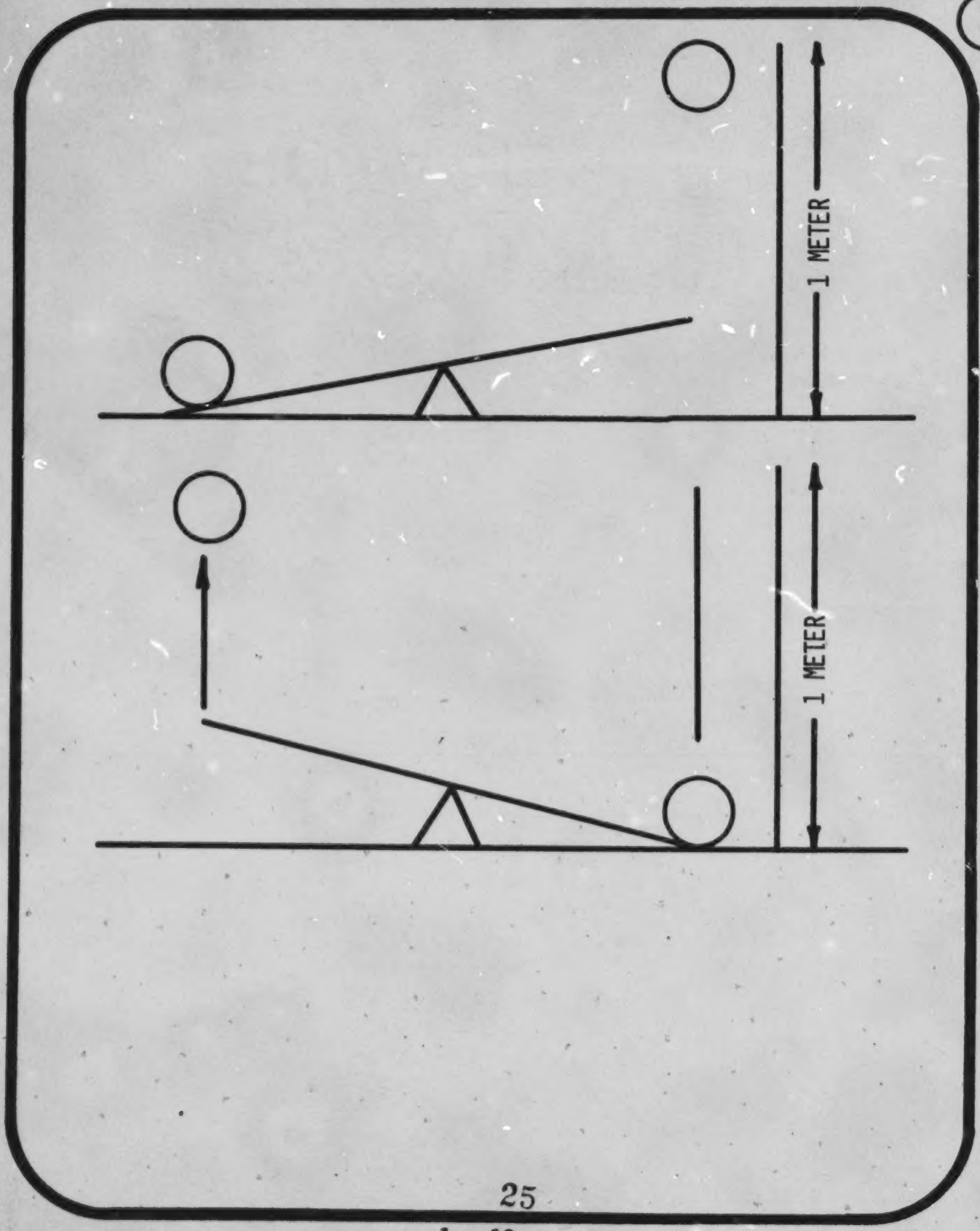
2. DESIGNATE A STUDENT TO HOLD A METER STICK VERTICALLY ON THE FLOOR. DESIGNATE A STUDENT TO LIFT AND DROP THE RUBBER BALLS, DESIGNATE A DATA RECORDER AND SEVERAL OBSERVERS.

3. INSTRUCT THE STUDENT TO SELECT A BALL AND LIFT IT TO A HEIGHT OF EXACTLY ONE METER. POINT OUT THAT IT TAKES ENERGY (KINETIC) TO LIFT THE BALL TO A HEIGHT OF ONE METER. ALSO, A CERTAIN AMOUNT OF WORK HAD TO BE DONE ON THE BALL (FORCE = WEIGHT OF BALL) AND DISTANCE = (METER) IN ORDER TO GET IT TO THE TOP OF THE METER STICK. FINALLY, THE BALL NOW POSSESSES A POTENTIAL ENERGY EQUAL TO THE WORK REQUIRED TO GET IT THERE. HAVE STUDENTS IMAGINE, BY USE OF VISUAL #7, THAT WHEN DROPPED IT WOULD STRIKE A TEETER-TOTTER WITH ANOTHER BALL ON THE OPPOSITE END.

   ASSUME THE SECOND BALL HAD THE SAME WEIGHT AS THE FIRST, AND THAT THE BAR HAD NO WEIGHT AT ALL. THEORETICALLY, THE FIRST BALL, WHEN DROPPED, WOULD LOSE POTENTIAL ENERGY AS IT FELL AND GAIN KINETIC ENERGY. UPON STRIKING THE BAR, IT WOULD LOSE BOTH KINETIC AND POTENTIAL ENERGY UNTIL IT REACHED THE FLOOR AT WHICH TIME IT WOULD HAVE 0 POTENTIAL AND 0 KINETIC ENERGY. SIMULTANEOUSLY, THE SECOND BALL WOULD HAVE ALL THE ENERGY, BUT MOSTLY KINETIC IN FORM.

7

VISUAL #



AS THE BALL ROSE TO A HEIGHT OF ONE METER, ITS KINETIC ENERGY WOULD BE REDUCED TO ZERO, BUT THE POTENTIAL ENERGY WOULD BE THE SAME AS THAT POSSESSED BY THE FIRST BALL WHEN DROPPED.

THE ABOVE DISCUSSION APPEARS TO BE CIRCULAR, AND THAT IS PRECISELY THE POINT, POTENTIAL ENERGY, KINETIC ENERGY AND WORK ARE ALL INTERCHANGIABLE FROM ONE TO THE OTHER.

4. INSTRUCT THE STUDENT TO DROP THE BALL AND HAVE THE OBSERVERS DESCRIBE WHAT HAPPENED. RECORD THE RESULTS.

A. DID THE BALL BOUNCE BACK TO A HEIGHT OF ONE METER?
B. WHY NOT?
C. WHY DID THE BALL BOUNCE AT ALL?

THE BALL BOUNCED PRIMARILY BECAUSE THE HARD FLOOR WAS NOT ABLE TO MOVE AND THUS ABSORB THE ENERGY. WORK = FORCE X DISTANCE. IN THIS CASE, THE DISTANCE THE FLOOR MOVED IS ALMOST 0; THEREFORE, WORK = 0 METERS X F = 0. SINCE THE FLOOR ABSORBED PRACTICALLY 0 ENERGY, NEARLY ALL OF IT WAS REFLECTED BACK TO THE BALL WHICH BOUNCED UP. SO WE HAVE THE SAME SERIES OF EVENTS AS WITH THE TEETER-TOTTER.

1. WORK WAS DONE ON THE BALL TO GIVE IT POTENTIAL ENERGY.
2. WHEN DROPPED IT WAS CONVERTED TO KINETIC ENERGY.
3. IT TRIED TO DO WORK ON THE FLOOR, BUT MOST WAS REFLECTED BACK IN THE FORM OF KINETIC ENERGY.
4. AS THE BALL ROSE, THE KINETIC AGAIN WAS CHANNELED TO POTENTIAL ENERGY.
5. REPEAT THE ABOVE STEPS WITH THE REST OF THE BALLS TO DETERMINE WHICH ONE IS MOST EFFICIENT AT INTERCHANGING WORK AND ENERGY STATES OR TYPES.

LECTURE NOTES

CURRICULUM GUIDE OUTLINE

1.30 HISTORICAL HARNESSING AND ENERGY USES

- 1.31 MUSCLE POWER
- 1.32 WATER AND WIND
- 1.33 HEAT AND STEAM
- 1.34 GRAVITY

THE CONCEPT EXPRESSED IN VISUAL #8 IS THAT MAN HAS, THROUGH THE CENTURIES, STEADILY INCREASED HIS KNOWLEDGE OF TOOLS WHICH WILL PERMIT HIM TO ACCOMPLISH MORE WORK IN LESS TIME WITH LESS EFFORT ON HIS PART.

EVENTUALLY, THIS KNOWLEDGE ACCUMULATED THROUGH EXPERIMENTATION, IMPROVED WRITTEN AND VERBAL COMMUNICATION AND TRANSPORTATION. THE RESULT WAS AN EXPLOSION OF PROGRESS WHICH IS TODAY REFERRED TO AS THE INDUSTRIAL REVOLUTION. THE ABOVE ELEMENTS CAME TOGETHER IN ENGLAND IN ABOUT THE YEAR 1700.

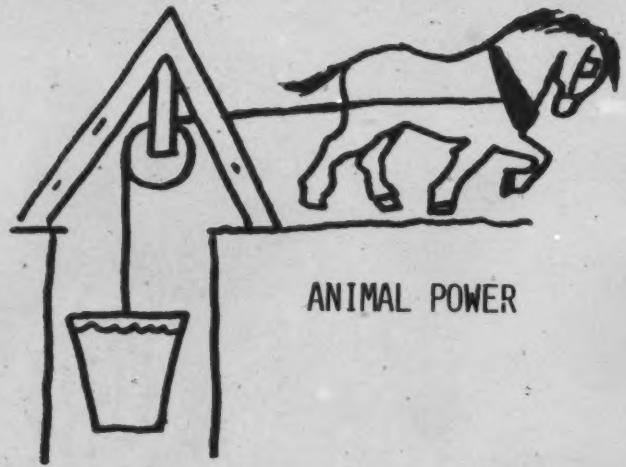
OTHER MORE SUBTLE FORCES, SUCH AS GOVERNMENT POLICY, WERE ALSO AT WORK AND SHOULD NOT BE OVERLOOKED. PARALLELS CAN BE FOUND TODAY IN THE STRUGGLE OVER GOVERNMENT DEREGULATION OF PRIVATE INDUSTRY.

REFER TO VISUAL #9 FOR SOME IMPORTANT MILESTONES IN THE INDUSTRIAL REVOLUTION.

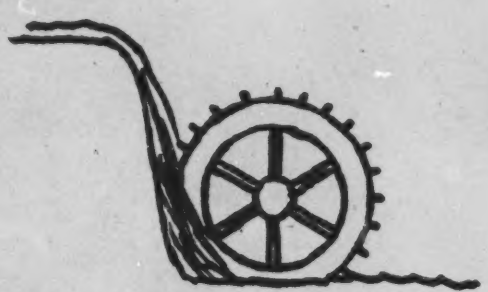
ASK STUDENTS TO IDENTIFY THOSE MILESTONES WHICH ARE AMERICAN. HOW IS IT THAT SO MANY INVENTIONS ARE AMERICAN WHEN THE INDUSTRIAL REVOLUTION OCCURRED IN ENGLAND? TECHNOLOGY TENDS TO PROLIFERATE RAPIDLY, AND THE COUNTRY POSSESSING THE MOST FAVORABLE CONDITIONS SOON BECOMES TECHNOLOGICALLY SUPERIOR. PARALLELS EXIST TODAY IN TERMS OF NUCLEAR TECHNOLOGY.

NEXT, ASK STUDENTS WHICH INVENTIONS ARE RELATED TO ENERGY AND POWER EITHER DIRECTLY OR ARE INDIRECTLY DEPENDENT UPON IT.

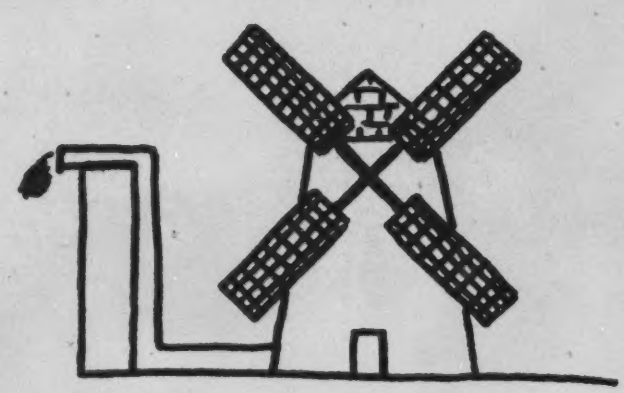
MUSCLE POWER



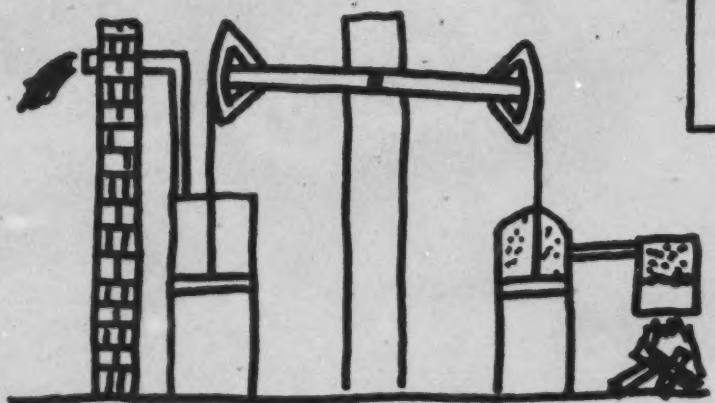
ANIMAL POWER



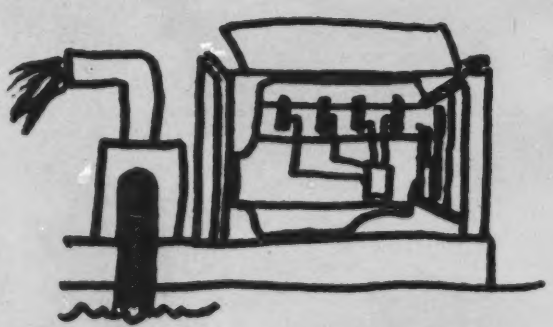
WATER POWER



WIND POWER



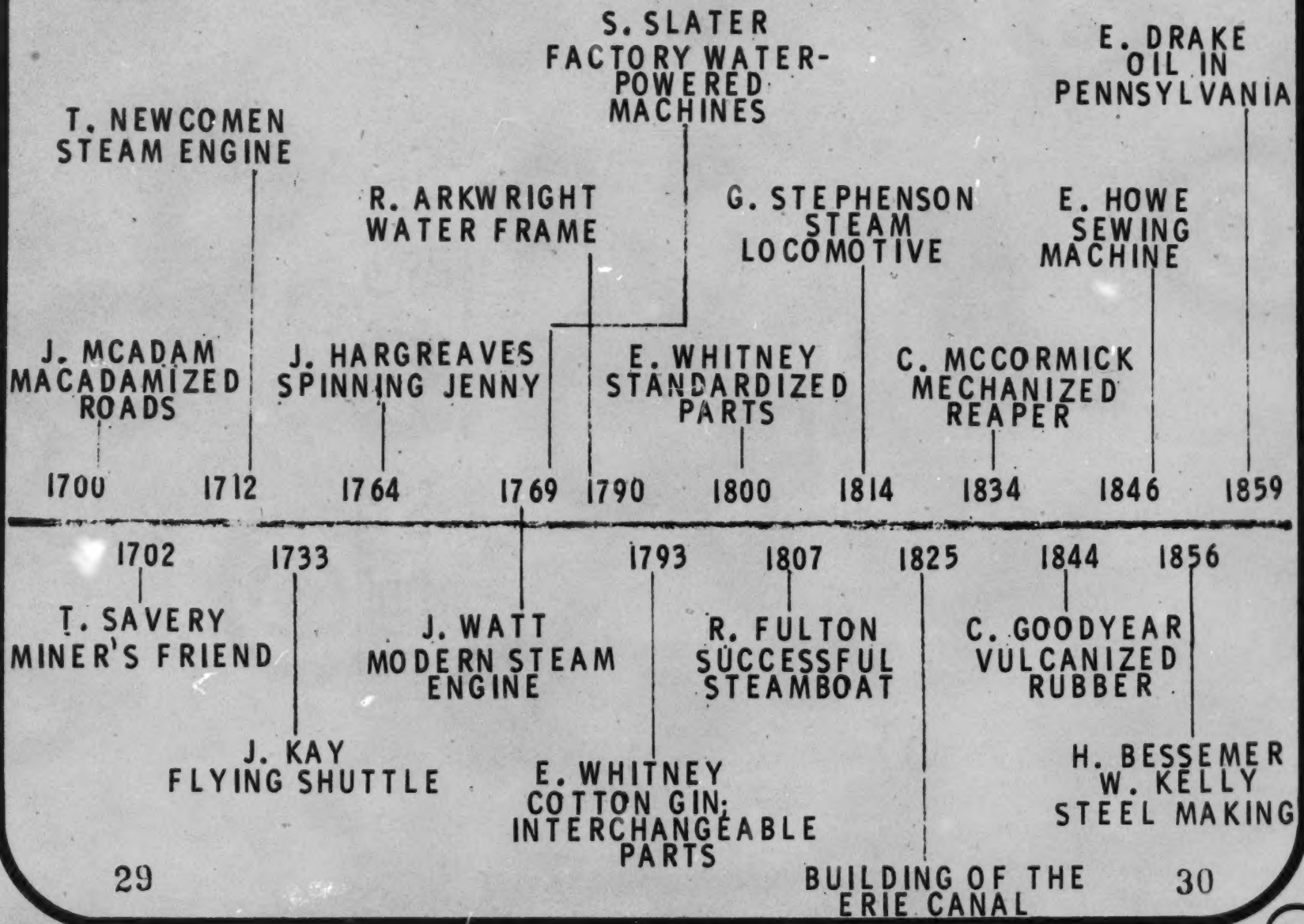
STEAM POWER



28

DIESEL POWER

THE INDUSTRIAL REVOLUTION 1700 - 1860



UNIT # 1 TOPIC 1.30 HISTORICAL HARNESSING AND ENERGY USES

VISUAL # 9

LECTURE NOTES

CURRICULUM GUIDE OUTLINE

1.40 BASIC MEASURANDS, BASIC AND DERIVED UNITS, AND INTER-RELATIONSHIPS.

1.41 ENERGY (JOULE)
1.42 POWER (WATT)
1.43 FORCE (NEWTON)
1.44 TORQUE (NEWTON-METER)
1.45 PRESSURE (PASCAL)
1.46 THERMAL ENERGY (CALORIE)
1.47 MASS, LENGTH, TIME, ETC.

1.41 UP TO THIS POINT, WE HAVE DEFINED ENERGY ONLY AS THE ABILITY TO DO WORK. WE HAVE ALSO DEALT WITH THE CONCEPT OF STORED ENERGY (POTENTIAL) AND ENERGY IN ACTION (KINETIC).

WE MUST NOW DEAL WITH QUANTIFICATION OR THE QUESTION OF "HOW MUCH." FIRST, LET US DEAL WITH MECHANICAL ENERGY OR WORK. TO DO SO, HOWEVER, WILL REQUIRE A DIGRESSION TO A DISCUSSION OF THE ENGLISH AND METRIC SYSTEMS OF MEASUREMENT AND THEN A JUMP AHEAD TO SUBTOPIC 1.47, BASIC UNITS.

IN THE ENGLISH SYSTEM WE ARE GUILTY OF A VERY SLOPPY USE OF TERMS, PARTICULARLY THOSE CONCERNING WEIGHT, FORCE, GRAVITY AND MASS. FOR EXAMPLE, MASS IS DEFINED AS A FIXED AMOUNT OF MATERIAL, WHILE WEIGHT IS THE FORCE OF GRAVITY PULLING ON THE OBJECT. WE OFTEN BUY THINGS BY THE POUND (FORCE OF GRAVITY).

IT SHOULD BE OBVIOUS THAT THE FARTHER AWAY FROM THE EARTH WE ARE, THE WEAKER THE PULL OF GRAVITY BECOMES.

THE MOST ACCURATE WAY TO MEASURE OR BUY THINGS IS BY MASS OR THE AMOUNT OF MATERIAL CONTAINED, NOT HOW MUCH IT "WEIGHS." IN THE ENGLISH SYSTEM THE UNIT OF MASS IS THE SLUG. IT IS SUCH A CUMBERSOME UNIT THAT MOST PEOPLE HAVE NEVER EVEN HEARD OF IT LET ALONE USE IT. RATHER THAN WASTE TIME DEFINING SUCH A UNIT, LET USE MOVE ON TO THE METRIC SYSTEM WHERE BOTH THE UNITS OF MASS AND FORCE (WEIGHT) ARE MORE USABLE. REFER TO THE VISUALS IN APPENDIX C FOR ENGLISH/METRIC CONVERSIONS AND PREFIXES AS NEEDED.

IN VISUAL #10 WE FIND THE DEFINITIONS OF MASS, FORCE, AND GRAVITY AND THE RESPECTIVE UNITS AS USED IN THE METRIC SYSTEM. THE DIFFERENCE BETWEEN THE ABOVE TERMS IS POINTED OUT BY VISUAL #11.

A SATELLITE HAS A MASS OF 10 KILOGRAMS AND WEIGHS 9.81 NEWTONS AT LAUNCH. BUT AS IT RISES, THE ATTRACTION OF THE EARTH BECOMES LESS AND FINALLY APPROACHES 0 (WEIGHTLESSNESS), BUT THE MASS REMAINS CONSTANT.

RETURNING TO THE DISCUSSION OF SUBTOPIC 1.41, WE CAN NOW DEFINE THE UNIT OF ENERGY OR WORK. REFER TO VISUAL #12.

WE CAN STORE ENERGY IN A NUMBER OF WAYS, AND AS A RESULT OTHER UNITS HAVE BEEN FORMULATED FOR CONVENIENCE. REFER TO VISUAL #13.

FOR EXAMPLE, IT IS USEFUL TO KNOW HOW MUCH HEAT IS STORED IN A GALLON OF GASOLINE. A CONVENIENT UNIT OF HEAT ENERGY MEASUREMENT IS THE CALORIE. A CALORIE IS THE AMOUNT OF HEAT THAT WILL RAISE A CUBIC CENTIMETER OF WATER 1^{0} CELSIUS. THIS IS AN EXTREMELY SMALL UNIT. THEREFORE, A LARGE CALORIE WAS DERIVED. THE CALORIE (SPELLED WITH A CAPITAL C) IS THE AMOUNT OF HEAT REQUIRED TO RAISE 1000 CUBIC CENTIMETERS OF WATER (1 LITER) OF WATER 1^{0} CELSIUS.

IN THE ENGLISH SYSTEM THE UNIT OF HEAT ENERGY IS THE BRITISH THERMAL UNIT OR BTU. THE BTU IS THE AMOUNT OF ENERGY REQUIRED TO RAISE A POUND OF WATER 1^{0} FAHRENHEIT.

THE CALORIE IS EQUAL TO APPROXIMATELY 4 BTUS.

CURRICULUM GUIDE OUTLINE

1.42 MOST TEACHERS RESPONSIBLE FOR TEACHING THE METRIC SYSTEM BELIEVE THAT IT IS UNWISE TO BE CONSTANTLY CONVERTING FROM ENGLISH TO METRIC JUST AS IT IS UNWISE WHEN TRYING TO TEACH A FOREIGH LANGUAGE. THE TRICK IS TO "SPEAK THE LANGUAGE", "THINK THE LANGUAGE," AND FORM LASTING MENTAL IMAGES, NOT TRANSLATIONS.

EVEN SO, THERE IS MUCH TO BE SAID FOR BEGINNING A DISCUSSION ON POWER WITH THE ENGLISH UNIT "THE HORSEPOWER."

32

DISCUSSION CONTINUES ON PAGE 1-21

VISUAL # 10

METRIC (SI) UNITS - APPROXIMATE

UNDER STANDARD CONDITIONS (SEALEVEL, 4°C)

MASS

A LITER OF PURE WATER HAS A MASS OF I KILOGRAM

UNIT OF MASS IS THE KILOGRAM

FORCE

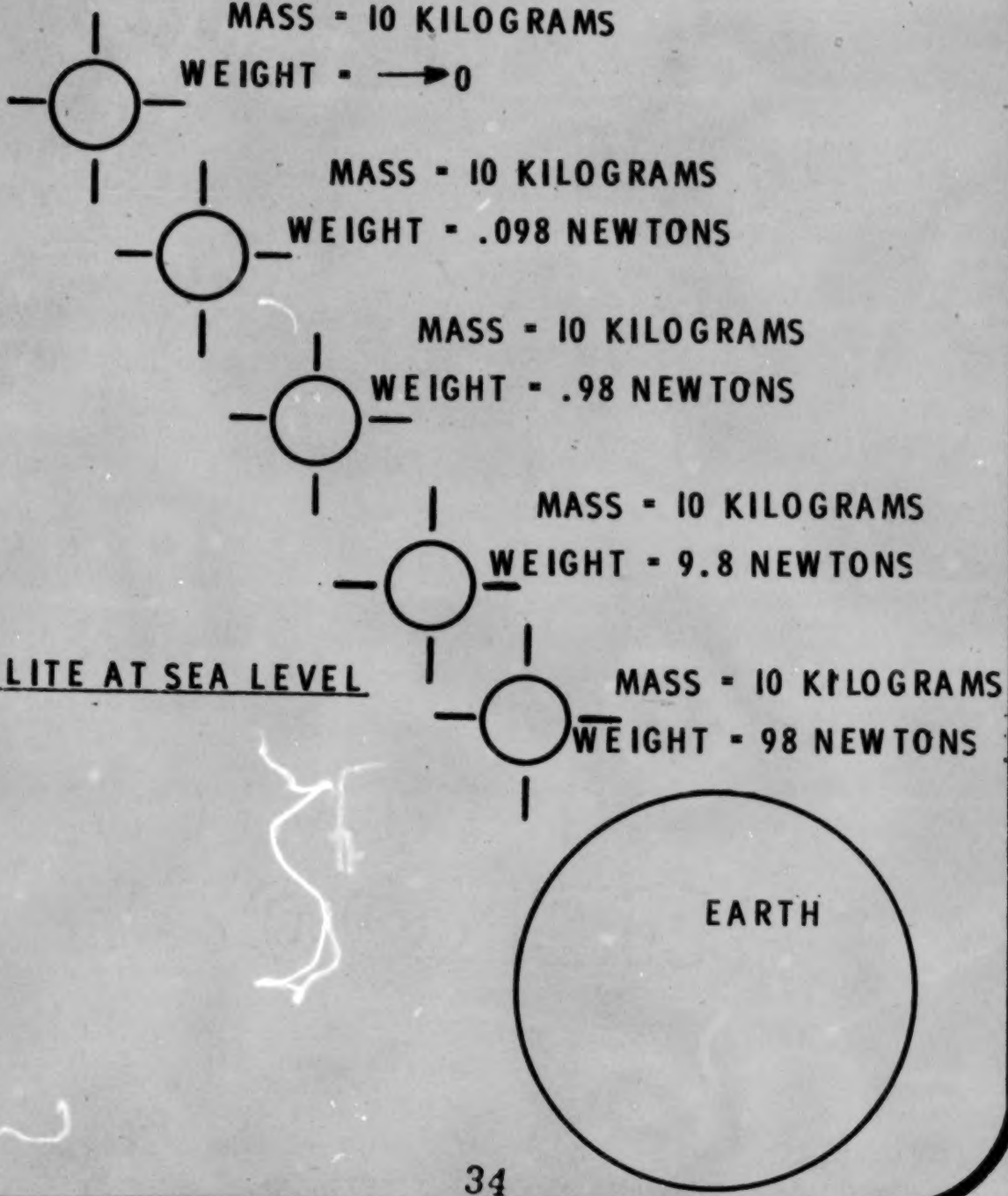
UNIT OF FORCE IS THE NEWTON

WEIGHT

A LITER OF WATER IS ATTRACTED TOWARD EARTH WITH A FORCE OF 9.81 NEWTONS.

CONVERSION

A LITER OF WATER HAS A MASS OF I KILOGRAM, AND WEIGHS 9.81 NEWTONS UNDER STANDARD CONDITIONS.


MASS - 10 KILOGRAMS
WEIGHT - → 0
MASS - 10 KILOGRAMS
WEIGHT - .098 NEWTONS
MASS - 10 KILOGRAMS
WEIGHT - .98 NEWTONS
MASS - 10 KILOGRAMS
WEIGHT - 9.8 NEWTONS
SATELLITE AT SEA LEVEL
MASS - 10 KILOGRAMS
WEIGHT - 98 NEWTONS
EARTH

34

ENERGY/WORK UNITS - MECHANICAL

WORK IS DONE WHEN A FORCE IS EXERTED AND MOVEMENT RESULTS.

WHEN: A FORCE OF 1 NEWTON IS EXERTED AND A MOVEMENT OF 1 METER RESULTS, WE HAVE ACCOMPLISHED A NEWTON-METER OF WORK.

A NEWTON-METER IS CALLED A JOULE

EXAMPLE: IF WE CARRY A CONTAINER WEIGHING 1 NEWTON UP A STAIRS WHICH IS 10 METERS HIGH, WE HAVE DONE 10 JOULES OF WORK. ALSO, THE CONTAINER NOW HAS THE ABILITY (POTENTIAL ENERGY) TO DO 10 JOULES OF WORK ON THE FLOOR SHOULD IT FALL. AS YOU WOULD EXPECT, THE UNIT OF WORK IN THE ENGLISH SYSTEM IS THE POUND-FOOT.

ONE JOULE = APPROXIMATELY .75 POUND-FOOT.

VISUAL # 13

ENERGY/POWER UNITS - HEAT

I CALORIE IS: THE AMOUNT OF HEAT REQUIRED TO RAISE THE TEMPERATURE OF A CUBIC CENTIMETER OF WATER 1° CELSIUS.

I CALORIE (CAPITAL C) IS: THE AMOUNT OF HEAT REQUIRED TO RAISE THE TEMPERATURE OF A LITER (1000 CUBIC CENTIMETERS) OF WATER 1° CELSIUS.

THE CALORIE OR KILOCALORIE IS THE UNIT REFERRED TO WHEN CALCULATION THE ENERGY CONTAINED IN THE FOOD WE EAT.

EXAMPLE: A 1000 CALORIE MEAL CONTAINS ENOUGH ENERGY TO RAISE THE TEMPERATURE OF A 1000 LITERS OF WATER 1° CELSIUS. (1.8 FAHRENHEIT) !

EXAMPLE: A GALLON OF GASOLINE CONTAINS OVER 30 TIMES AS MUCH ENERGY AS A 1000 CALORIE MEAL.

1 CALORIE = 4184 JOULES OF MECHANICAL ENERGY
1 CALORIE = 4 BTU APPROXIMATELY

FIRST OF ALL, THE TERM "HORSEPOWER" PROVIDES A MENTAL IMAGE FOR COMPARISON NOT FOUND WITH THE "WATT." SECONDLY, FROM AN HISTORIC STANDPOINT THE EPISODE OF JAMES WATT AND HIS STEAM ENGINE IS WORTHWHILE. AND THIRD, THE CONCEPT OF POWER IS SO IMPORTANT IN AN ENERGY/POWER COURSE THAT EVERY TOOL MUST BE USED TO GET THE CONCEPT ACROSS. INDEED, JAMES WATT HAD THE SAME PROBLEM. REFER TO VISUALS #14-18.

IT IS SUGGESTED THAT AFTER A REVIEW OF THESE CONCEPTS, ONE OF THE FOLLOWING STUDENT ACTIVITIES SHOULD BE USED TO PERSONALIZE THE CONCEPT OF POWER:

BICYCLE ACTIVITY
BARBELLS ACTIVITY
STAIRS ACTIVITY

SEE APPENDIX D FOR NOTES ON BUILDING THE BICYCLE TRAINER. ADMITTEDLY, THE TRAINER WILL TAKE SEVERAL HOURS TO CONSTRUCT, BUT IT IS ALSO USABLE FOR DEMONSTRATING THE METRIC UNIT OF POWER, THE WATT, AND LATER ON CONVERSION FROM MECHANICAL POWER TO ELECTRICAL, AND ALSO POWER TRANSMISSION AND GEAR RATIOS.

NEXT REFER TO VISUALS # 19-24 FOR A DISCUSSION OF THE METRIC MECHANICAL POWER UNIT, THE WATT , AND ELECTRICAL RELATIONSHIPS; AND FINALLY, THE UNIT OF ELECTRICAL POWER, ALSO THE "WATT."

WHEN PERFORMING THE EXPERIMENT SHOWN IN VISUAL # 24 THE MOST STRIKING OBSERVATION IS THAT THE AMOUNT OF ELECTRICAL POWER PRODUCED IS ONLY A FRACTION OF THE POWER PRODUCED IN THE EXPERIMENT SHOWN IN VISUAL #16. THERE ARE SEVERAL REASONS FOR THIS. FIRST, WHENEVER POWER IS CONVERTED FROM ONE FORM TO THE OTHER, THERE ARE MANY SOURCES OF LOSSES. ONE OF THE LARGEST LOSSES IN THIS SYSTEM IS THE METHOD OF PRODUCING A MAGNETIC FIELD TO CUT THROUGH THE WINDINGS. THIS PROBLEM COULD BE ELIMINATED BY USING A PERMANENT MAGNET. HOWEVER, WE ARE USING AN ELECTRIC CURRENT TO PRODUCE A MAGNETIC FIELD. MOST OF THE POWER A PERSON CAN PRODUCE IS CONSUMED BY THE ROTATING ELECTROMAGNET AND LITTLE POWER IS LEFT TO LIGHT THE LAMPS (USEFUL POWER). WE CAN CUT THESE LOSSES SOMEWHAT BY INSERTING A PIECE OF NICHROME HEATING ELEMENT WIRE IN THE JUMPER AS SHOWN ON THE DIAGRAM. BY USING AN ALLIGATOR CLIP TO SHORT A PORTION OF THE WIRE, WE CAN ADJUST ITS LENGTH TO OBTAIN THE MAXIMUM USABLE POWER.

LECTURE NOTES

IF YOU CONSTRUCT THE BICYCLE TRAINER AS A CLASS PROJECT, REFER TO THE FOLLOWING TWO STUDENT EXPERIMENTS, MECHANICAL POWER AND ELECTRICAL POWER. IF NOT, AN ALTERNATE EXPERIMENT SUCH AS RUNNING A STAIRS OR LIFTING A BARBELL MAY BE PERFORMED. EXPERIMENTS ON P. 1-36.

RETURNING TO THE CURRICULUM GUIDE OUTLINE, WE HAVE DISCUSSED ALL UNITS AND CONCEPTS UNDER 1.40 EXCEPT 1.44, TORQUE, AND 1.45, PRESSURE. REFER TO VISUAL # 25 FOR A DISCUSSION OF TORQUE. IN THE METRIC SYSTEM THERE IS LITTLE CONFUSION BETWEEN THE UNIT FOR WORK AND THE UNIT FOR TORQUE SINCE THERE IS A SEPARATE TERM (JOULE) TO DESCRIBE WORK. IN THE ENGLISH SYSTEM THE UNIT FOR WORK IS THE POUND-FOOT AND THE UNIT FOR TORQUE IS THE FOOT-POUND WITH SOME CONFUSION AND MISUSE OF TERMS TO REPRESENT TWO ENTIRELY DIFFERENT CONCEPTS.

REFER TO VISUAL #26 FOR A DISCUSSION OF PRESSURE. A COMMON POINT OF MISUNDERSTANDING IS THE DIFFERENCE BETWEEN PRESSURE AND FORCE. PRESSURE CAN BE DEFINED AS FORCE PER UNIT AREA. WHILE FORCE IS NOT RESTRICTED TO A UNIT AREA, RATHER THE TERM IS USUALLY USED WITH RESPECT TO AN ENTIRE SURFACE. ONE EXAMPLE USING METRIC UNITS IS GIVEN IN THE VISUAL. ANOTHER EXAMPLE ILLUSTRATING THE DIFFERENCE BETWEEN PRESSURE AND FORCE IS THE AUTO TIRE. A PRESSURE OF ONLY 20 LBS. PER SQUARE INCH IN A TIRE WILL EASILY LIFT A CAR WEIGHING THOUSANDS OF POUNDS BECAUSE THERE ARE THOUSANDS OF SQUARE INCHES ON THE INNER SURFACE OF A TIRE MULTIPLIED BY 20 WHICH GIVES US TOTAL FORCE.

HORSE POWER (ENGLISH SYSTEM)

JAMES WATT, AN ENGLISHMAN, HAD TROUBLE GETTING PEOPLE OF THE TIME TO APPRECIATE THE VALUE OF HIS STEAM ENGINE. (1765).

AT THAT TIME, HORSES WERE USED TO LIFT WATER OUT OF COAL MINES. ALSO, MOST PEOPLE UNDERSTOOD HORSES AND THE WORK THEY COULD DO.

SO, JAMES WATT HIT UPON THE IDEA OF COMPARING HIS STEAM ENGINE WITH HORSES. HE DISCOVERED THAT A GOOD HORSE COULD LIFT 330 LBS. OF WATER FROM A 100 FT. SHAFT IN ONE MINUTE.

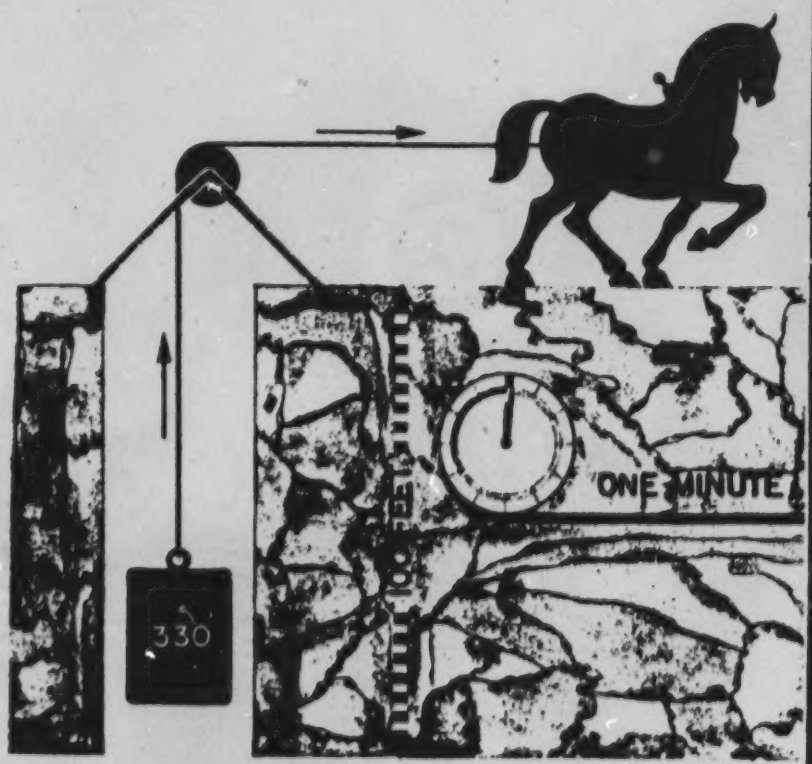
$$1\ HP = \frac{330\ LBS \times 100\ FT}{1\ MIN.}$$

OR

$$1\ HP = \frac{33{,}000\ LB\ FT}{MIN}$$

IF HIS STEAM ENGINE COULD LIFT 3,300 LB 100 FT IN 1 MIN. THEN

$$H.P. = \frac{3{,}300 \times 100}{33{,}000} = 10$$



HORSE POWER & MAN POWER

OR

MAN POWERED FLIGHT

FOR THOUSANDS OF YEARS, MAN HAS DESIRED TO FLY, FIRST ON HIS OWN POWER, THEN WITH MACHINES. UNTIL THE WRIGHT BROTHERS FLIGHT OF 1903, MOST THOUGHT MAN COULD NOT FLY BY ANY MEANS. AFTER THE WRIGHT BROTHERS SUCCESS, SCIENTISTS BECAME CONVINCED MAN COULD NEVER FLY ON HIS OWN POWER. BUT DUE TO THE ADVANCES IN ENGINEERING AND LIGHTER, STRONGER MATERIALS, PILOT BRIAN ALLAN AND DESIGNER PAUL MacREADY PROVED IT COULD BE DONE ON AUGUST 23, 1977, BY FLYING A FIGURE 8 COURSE AT AN ALTITUDE OF 10 FT. IN DOING SO, THEY COLLECTED A 50,000 POUND PRIZE, UNCOLLECTED SINCE OFFERED IN 1959 BY A BRITISH INDUSTRIALIST. THE PILOT AVERAGED .43 H.P. FOR THE 7 MIN. FLIGHT. COULD YOU?

TWO YEARS LATER, THE SAME INDUSTRIALIST PAID 100,000 POUNDS TO THE SAME TEAM FOR THE FIRST MAN-POWERED CROSSING OF THE ENGLISH CHANNEL. THE FIRST PLANE WAS CALLED THE GOSSAMER CONDOR, THE SECOND THE GOSSAMER ALBATROSS. BELOW ARE SOME OF THE SPECIFICATIONS OF THE TWO PLANES

	CONDOR	ALBATROSS
WEIGHT	70 LBS (315 NT)	50 LBS (225 NT)
WINGSPAN	96 FT. (29 M)	96 FT. (29)
HEIGHT	18 FT. (5.4 M)	18 FT. (5.4 M)
LENGTH	30 FT. (9 M)	30 FT. (9 M)
SPEED	11 MPH (17 KMH)	13.7 MPH (22 KMH)
FLIGHT	FIGURE 8,1 MILE (1.6KM)	CHANNEL CROSSING 25MI
ALTITUDE	AT LEAST 10 FT. (3M)	LESS THAN 50 FT. (15M)
DURATION	APPROX 7 MIN.	2 HRS, 49 MIN
PRIZE	$86,000	$172,000

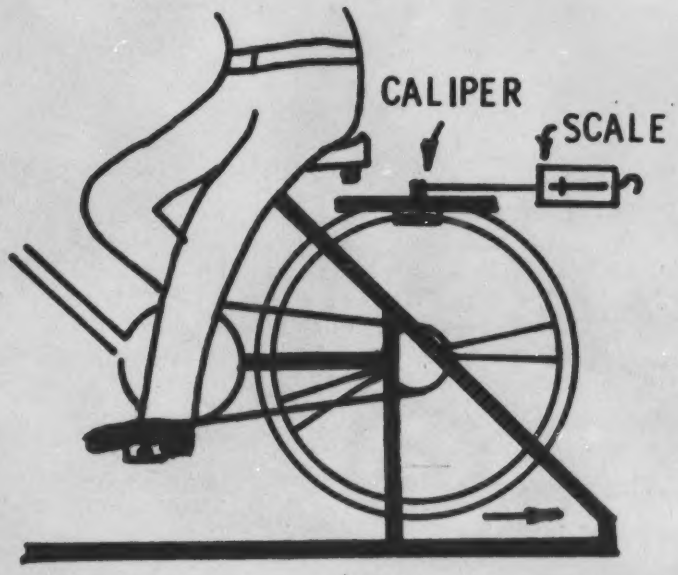
40

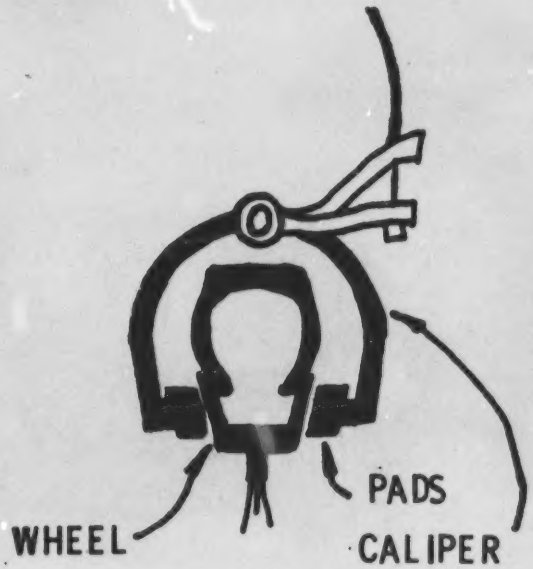
16

VISUAL #

CHECKING YOUR HORSE POWER

YOU CAN CHECK YOUR PEAK HORSE POWER OUTPUT BY USING A BICYCLE, BRAKE CALIPER, FISH SCALE AND A BIKE SPEEDOMETER. NOTE THAT THE FORCE PULLING THE SCALE FORWARD IS EQUAL TO THE FORCE THAT THE WHEEL EXERTS ON THE ROAD.





EXAMPLE: YOU EXERT 10 LB FORCE @ 25 M.P.H.
DIVIDE 25 BY 60 TO GET MILES PER MINUTE = .4166
MULTIPLY .4166 M.P.M. x 5280 TO GET FEET = 2200 FT
MULTIPLY 2200 x 10 LB TO GET WORK = 22,000 LB FT
DIVIDE 22,000 BY 33,000 TO GET H.P. = .66 HP

41

FORMULA: $HP = \frac{M.P.H. \times 5280 \times FORCE}{60 \times 33{,}000}$

YOUR H.P. = $\frac{\quad \times 5280 \times}{60 \times 33{,}000}$

TO FLY, YOU NEED .43 H.P. FOR 7 MINUTES.

CAN YOU FLY?

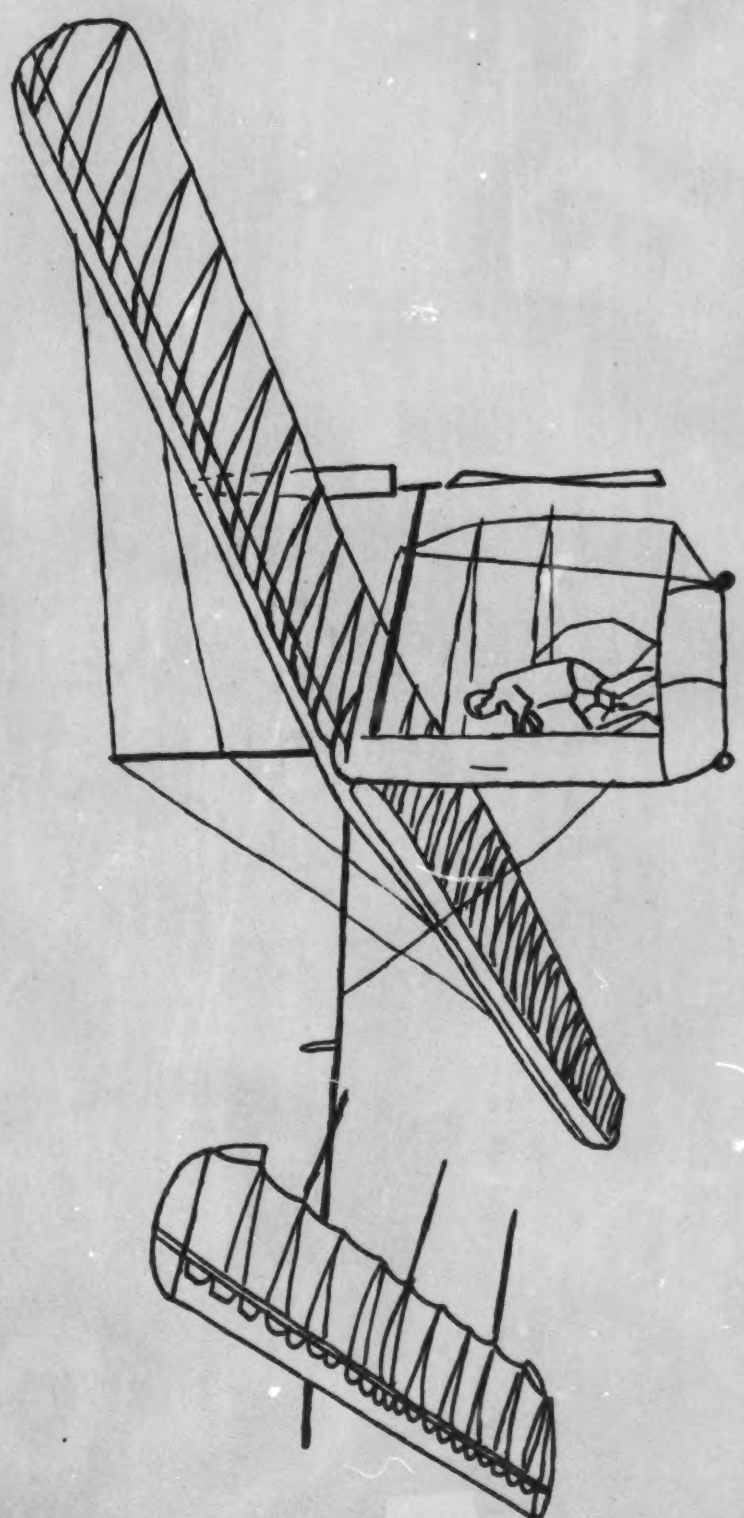
AFTER THE FIRST MAN-POWERED FLIGHT WAS ACCOMPLISHED, THE SAME MAN WHO OFFERED THE 50,000 POUND PRIZE OFFERED 100,000 POUNDS TO THE TEAM OR INDIVIDUAL FIRST TO CROSS THE ENGLISH CHANNEL ON MAN POWER ALONE. THE SAME TEAM OF ALLEN AND MacCREADY BUILT A NEW PLANE CALLED THE ALBATROSS, MUCH LIGHTER AND REQUIRING LESS POWER. IT WAS ESTIMATED THAT IT WOULD REQUIRE .35 H.P. FOR 1 - 1 1/2 HOURS. DURING THE SUMMER OF 1979, THE ATTEMPT WAS MADE. IT WAS SUCCESSFUL BUT,BECAUSE OF HEAD WINDS, THE FLIGHT TOOK NEARLY 2 1/2 HOURS. COULD YOU AVERAGE .35 H.P. FOR 2 1/2 HOURS?

MEASURE YOUR H.P. AND FIND OUT.

18

VISUAL #

THE GOSSAMER ALBATROSS - FIRST MAN-POWERED FLIGHT ACROSS THE ENGLISH CHANNEL



44

43

POWER AS MEASURED IN THE METRIC SYSTEM

THE METRIC UNIT FOR DISTANCE, THE METER (3.25 FT), AND THE UNIT OF FORCE, NEWTON (2.2 LB) COMBINE TO MAKE THE METRIC UNIT FOR WORK, THE NEWTON METER OR JOULE. THE STANDARD TIME UNIT IN THE METRIC SYSTEM IS THE SECOND, NOT THE MINUTE. THEREFORE, THE METRIC UNIT FOR POWER IS:

$P = \frac{N \times M}{S}$ OR NEWTON METER PER SECOND.

BECAUSE METRIC SYSTEM EVOLVED AT A LATER POINT IN HISTORY, THE NEWTON METER PER SECOND WAS GIVEN A SPECIAL NAME IN HONOR OF JAMES WATT:

1 WATT = 1 NEWTON METER PER SECOND

BY WAY OF COMPARISON, THE WATT IS A VERY SMALL UNIT:

1 H.P. = 746 WATTS.

20

VISUAL #

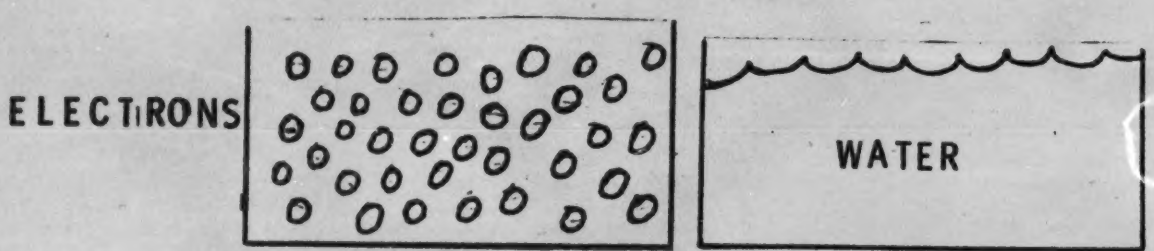
ELECTRICAL RELATIONSHIPS

ELECTRICITY IS GENERALLY HELD TO BE THE MOVEMENT OF CHARGES, USUALLY ELECTRONS, DOWN A WIRE FOR THE PURPOSE OF DOING USEFUL WORK.

ELECTRICAL POWER CAN BE COMPARED QUITE NICELY TO MECHANICAL POWER EXCEPT THAT IT BEHAVES LIKE A FLUID SUCH AS WATER. THEREFORE WE WILL BE COMPARING IT TO WATER POWER RATHER THAN TO WHEELS, GEARS, LEVERS, AND PRECISE DISTANCES.

VOLTAGE – THE UNIT OF ELECTRICAL PRESSURE IS THE VOLT. ONE VOLT COULD BE COMPARED TO ONE POUND PER SQUARE INCH OF WATER PRESSURE IN A TANK OF WATER.

CHARGE – THE UNIT OF CHARGE IS CALLED A COULOMB. IT IS A FIXED QUANTITY THAT COMPARES NICELY WITH A GALLON OR LITER OF WATER.



1 COULOMB 1 LITER–1 GALLON

21

VISUAL #

THERE ARE 6,280,000,000,000,000,000 ELECTRONS IN A COULOMB. BECAUSE THE BASIC RELATIONSHIPS IN ELECTRICITY WERE DISCOVERED AT ABOUT THE SAME TIME AS THE METRIC SYSTEM, IT WAS OBVIOUS THAT THE ELECTRICAL UNIT FOR POWER AND THE MECHANICAL UNIT HAD TO BE THE SAME: THE WATT.

LATER, WHEN ELECTRONS WERE DISCOVERED THIS OUTRAGEOUS NUMBER RESULTED. IN REALITY, THIS NUMBER CONCERNS US NO MORE THAN THE NUMBER OF MOLECULES IN A LITER OF WATER.

CURRENT - THE UNIT FOR CURRENT IS THE AMPERE. IT COMPARES NICELY WITH THE RATE OF WATER FLOW WHICH IS GALLONS PER MINUTE OR LITERS PER SECOND. AN AMPERE IS DEFINED AS A RATE OF FLOW OF ONE COULOMB PER SECOND PAST GIVEN POINT.

COULOMBS PER SEC → (AMPS)

WIRE

→ GAL. I MIN.

WATER PIPE

22

VISUAL #

RESISTANCE - THE UNIT OF RESISTANCE IS THE OHM. IT COMPARES NICELY WITH THE DIAMETER OF A PIPE OR A FAUCET. FOR EXAMPLE A LARGE PIPE HAS LITTLE RESISTANCE TO WATER FLOW. A SMALL PIPE HAS A LARGE RESISTANCE. A FAUCET CAN HAVE A SMALL OR A LARGE RESISTANCE TO THE FLOW OF WATER.

OHMS LAW - OHMS LAW SAYS THAT VOLTAGE (PRESSURE) EQUALS AMPS (GAL. PER MIN) TIMES RESISTANCE (PIPE RESTRICTION). IN OTHER WORDS, IF PRESSURE (VOLTAGE) INCREASED, THEN VOLUME (AMP) MUST INCREASE IF PIPE SIZE STAYS THE SAME (RESISTANCE). LIKEWISE, IF PRESSURE DECREASES, THAN VOLUME (AMPERAGE) MUST DECREASE IF THE PIPE DIAMETER REMAINS UNCHANGED. STATED MATHEMATICALLY, THIS RELATIONSHIP IS:

VOLTAGE = CURRENT x RESISTANCE

VISUAL # 23

WATTS LAW - ELECTRICAL POWER

WATTS LAW - STATES THAT VOLTAGE TIMES AMPERAGE = POWER

OR

WATTAGE = VOLTAGE x AMPERAGE

THIS SIMPLE FORMULA IS CORRECT BECAUSE IT CONTAINS THE SAME ELEMENTS AS THE MECHANICAL POWER FORMULA:

$$\text{POWER} = \frac{\text{FORCE} \times \text{DISTANCE}}{\text{TIME}}$$

WE CAN THEN SUBSTITUTE ELECTRICAL VALUES:

$$\text{POWER (WATTAGE)} = \text{FORCE (VOLTAGE)} \times \frac{\text{DISTANCE (COULOMBS)}}{\text{SEC}}$$

IN THE SUBSTITUTIONS ABOVE, COULOMBS PAST A GIVEN POINT REPRESENTS DISTANCE. SINCE COULOMBS PER SECOND EQUALS AMPS, THEN FORCE, DISTANCE, AND TIME ARE ALL REPRESENTED.

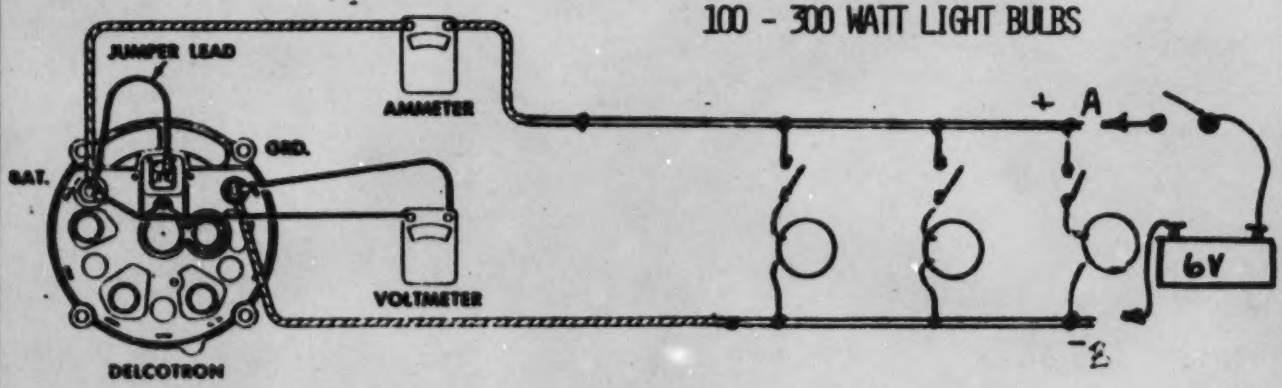
WATTS = VOLTAGE x CURRENT.

CHECKING YOUR WATTAGE

AUTO ALTERNATOR

ALTERNATOR - LOAD HOOK UP

100 - 300 WATT LIGHT BULBS



NOTE: AN ALTERNATOR IS NOT SELF-EXITING, THAT IS, A BATTERY MUST BE USED TEMPORARILY TO PRODUCE A MAGNETIC FIELD IN THE FIELD WINDINGS. ONCE AN OUTPUT IS PRODUCED, SOME CURRENT IS FED BACK TO THE FIELDWINDING, MAKING THE BATTERY UNNECESSARY.

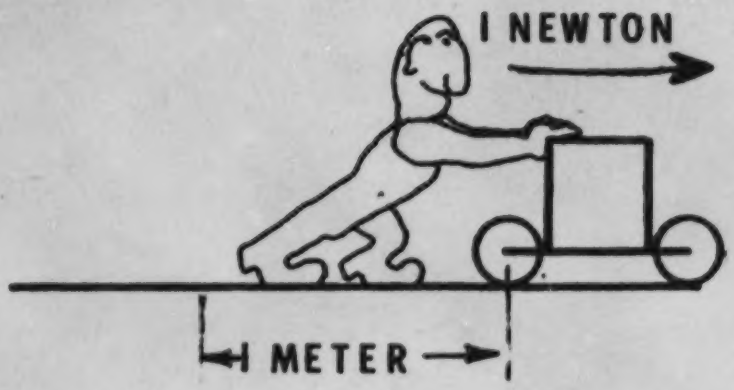
CONNECT A 6-12V LANTERN BATTERY FROM POINTS A TO B (BAT. TO GND) WHILE PEDALING. WHEN GENERATOR STARTS TO CHARGE, DISCONNECT BATTERY.

YOUR WATTAGE IS: _____ VOLTS x _____ AMPS = _____ WATTS

YOUR ELECTRICAL H.P. IS: _____ WATTS 746 = _____ H.P.

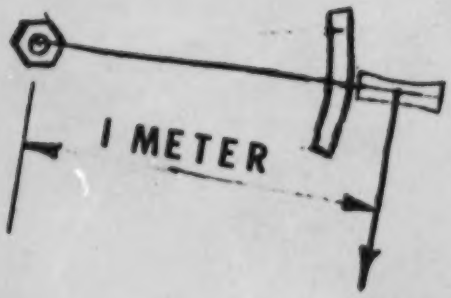
25

VISUAL #



WORK =
NEWTON-METER
= JOULE

TORQUE = A PERPENDICULAR TWISTING FORCE OF I NEWTON OPERATING AT A DISTANCE OF ONE METER = I NEWTON-METER



I NEWTON

IN THE ENGLISH SYSTEM	IN THE METRIC SYSTEM
WORK = POUND FOOT	WORK = JOULE
TORQUE = FOOT POUND	TORQUE = NEWTON-METER

51

VISUAL # 26

FORCE DEFINED: The cause of motion or the change or stoppage of motion of a body.

PRESSURE DEFINED: Force per unit area.

IN THE METRIC SYSTEM THE UNIT FOR PRESSURE IS THE NEWTON PER SQUARE METER OT THE PASCAL.
IN THE ENGLISH SYSTEM THE UNIT OF PRESSURE IS THE POUND PER SQUARE INCH.
EXAMPLE:

THE WIND EXERTS A PRESSURE OF 10 PASCALS (10 NEWTONS PER SQUARE METER) ON A SAIL. BECAUSE THERE ARE 10 SQUARE METERS OF SAIL, THERE IS TOTAL FORCE OF 100 NEWTONS PUSHING THE BOAT.

STUDENT LABORATORY EXPERIMENT

NAME **DATE** **EXPERIMENT** MECHANICAL POWER

OBJECTIVE:

TO REINFORCE CONCEPT THAT POWER IS A RATE OF DOING WORK.

EQUIPMENT:

BICYCLE POWER TRAINER

MATERIALS/COMPONENTS:

INCLUDED ON TRAINER

PROCEDURE:

1. DESIGNATE A HELPER TO PEDAL BICYCLE.
2. DESIGNATE A HELPER TO ADJUST CALIPER DRAG.
3. DESIGNATE A HELPER TO OBSERVE PEAK SPEED AND MAXIMUM FORCE REGISTERED ON SCALE. THIS MUST BE DONE AT THE SAME INSTANT.
4. RECORD PEAK SPEED =

   RECORD PEAK FORCE =
5. ASK YOUR INSTRUCTOR TO SHOW YOU VISUAL #16 FOR REVIEW.
6. DIVIDE THE PEAK SPEED RECORDED BY 60 TO GET MILES PER MINUTE =
7. MULTIPLY MILES PER MINUTE BY 5280 TO GET FEET TRAVELED =
8. MULTIPLY DISTANCE TRAVELED TIMES PEAK FORCE TO GET THE AMOUNT OF WORK DONE = _____ IN POUND-FEET.
9. IF WE ARE TO COMPARE THE AMOUNT OF WORK WE HAVE DONE WITH THAT WHICH A HORSE COULD DO, WE MUST DIVIDE BY 33,000 POUND-FEET.

$$H.P. = \frac{\text{(POUND-FEET) YOUR WORK}}{\text{(POUND-FEET/MIN) HORSE'S WORK}}$$

$$\frac{\quad}{33{,}000}$$

10. ANALYSIS: A STRONG STUDENT SHOULD BE ABLE TO DEVELOP OVER A HALF OF A HORSEPOWER FOR A SHORT TIME. HOWEVER, A HORSE COULD COMFORTABLY DO THIS ALL DAY.

11. ASK A FRIEND TO TRY TO MAINTAIN THE MAXIMUM RATE FOR 1, 2, 3, OR EVEN 5 MINUTES. RESULT? _____

12. IS THERE ANYONE IN CLASS WHO COULD DEVELOP AND MAINTAIN .35 H.P. FOR 2 1/2 HOURS AS DID BRYAN ALLEN IN THE FIRST MAN-POWERED FLIGHT ACROSS THE ENGLISH CHANNEL?

13. REPEAT STEPS 4, 6, 7, 8, AND 9 IN NEWTONS, METERS, AND WATTS. (MOST SPEEDOMETERS AND SCALES HAVE DUAL FACES; IF NOT, ASK INSTRUCTOR FOR CONVERSIONS.)

REMEMBER: A. SINCE WE ARE NOT COMPARING OURSELVES WITH HORSES, WE DO NOT DIVIDE BY 33,000.

B. SINCE THE TIME UNIT IN THE METRIC SYSTEM IS THE SECOND, NOT THE MINUTE, WE MUST DIVIDE PEAK SPEED BY 3600 INSTEAD OF 60 IN STEP 6 TO GET KM PER SEC.

STUDENT LABORATORY EXPERIMENT

NAME **DATE** **EXPERIMENT** ELECTRICAL POWER

OBJECTIVE:

TO SHOW THAT ELECTRICAL POWER IS ALSO A RATE OF DOING WORK.

EQUIPMENT:

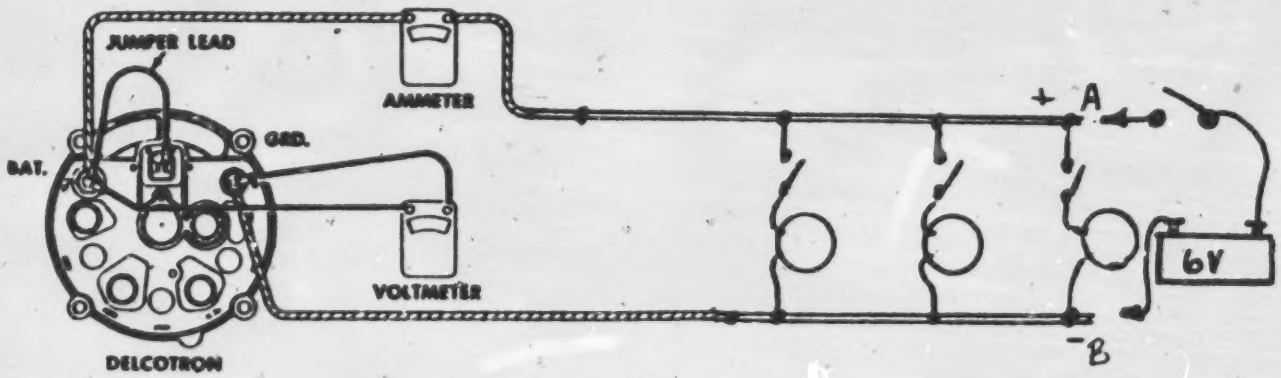
BICYCLE POWER TRAINER

MATERIALS/COMPONENTS:

AUTO-ALTERNATOR ON BASE
LIGHT BULB LOAD (3 BULBS IN PARALLEL)
1 AMMETER (10 AMP.)
1 VOLTMETER
1 SPOOL NICHROME WIRE
1-6V LANTERN BATTERY
1 KNIFE SWITCH
MISC. HOOK-UP WIRE

PROCEDURE:

1. HOOK UP ALTERNATOR AS SHOWN BELOW.



2. ADJUST TIRE AIR PRESSURE TO PROVIDE TRACTION WITHOUT EXCESS FRICTION.
3. ENLIST A FRIEND TO PEDAL BICYCLE.
4. CLOSE SWITCH TO 6V BATTERY FOR JUST A FEW SECONDS WHILE PEDALING. WHEN AN OUTPUT VOLTAGE APPEARS, DISCONNECT BATTERY. SEE VISUAL #25 FOR REVIEW.
5. CLOSE VARIOUS SWITCHES TO THE LIGHT BULB LOADS, AND/OR SUBSTITUTE DIFFERENT SIZE LIGHT BULBS TO OBTAIN MAXIMUM VOLTAGE AND CURRENT.

MAXIMUM VOLTAGE = _____

MAXIMUM CURRENT = _____

6. WHY IS THE ELECTRICAL POWER SO MUCH LESS THAN THE MECHANICAL POWER?
A PARTIAL EXPLANATION IS THAT MUCH POWER IS CONSUMED IN MAKING AN ELECTROMAGNET TO CUT THE WINDINGS.

7. TO IMPROVE USABLE OUTPUT SOMEWHAT, REMOVE JUMPER WIRE AND INSERT A PIECE OF NICHROME WIRE IN ITS PLACE.

8. REPEAT PREVIOUS STEPS WHILE ADJUSTING THE EFFECTIVE LENGTH OF THE NICHROME WIRE BY PARTIALLY SHORTING IT. CAUTION: THE WIRE WILL GET VERY HOT!

9. DID YOU SUCCEED IN RAISING OUTPUT POWER? IF YOU DID, YOU DID NOT PRODUCE MORE POWER, BUT SIMPLY WASTED LESS IN THE ELECTROMAGNET.

10. WHAT WAS YOUR FINAL PERCENTAGE OF EFFICIENCY COMPARED TO THE MECHANICAL POWER?

11. WHAT COULD BE DONE TO THE ALTERNATOR TO IMPROVE ITS EFFICIENCY?

STUDENT LABORATORY EXPERIMENT

ALTERNATE: WEIGHTLIFTING

NAME **DATE** **EXPERIMENT** MECHANICAL POWER

OBJECTIVE:

TO REINFORCE CONCEPT THAT POWER IS A RATE OF DOING WORK.

EQUIPMENT:

MATERIALS/COMPONENTS:

WATCH WITH SECOND HAND
BATHROOM OR WEIGHT ROOM SCALE
TAPE MEASURE
UP TO 100 POUNDS OF BARBELLS

PROCEDURE:

1. DESIGNATE A HELPER TO BE A TIMER.
2. DESIGNATE A HELPER TO COUNT NUMBER OF REPETITIONS.
3. ENLIST A FRIEND TO LIFT WEIGHTS.
4. MEASURE HEIGHT OF BAR WHEN AT SHOULDER LEVEL. _____
5. MEASURE HEIGHT OF BAR WHEN RAISED FULL HEIGHT. _____
6. SUBTRACT THE DIFFERENCE BETWEEN 4 AND 5. _____
7. SELECT A SET OF WEIGHTS THAT CAN BE LIFTED BY THE STUDENT CONTINUOUSLY FOR 1 MINUTE.
8. WEIGH COMPLETE BARBELL. _____
9. INSTRUCT STUDENT TO LIFT WEIGHTS FROM SHOULDER TO FULL EXTENDED AS MANY TIMES AS POSSIBLE FOR A FULL MINUTE.
10. BEGIN EXPERIMENT.
11. ROUND THE FIGURE OBTAINED IN STEP 6 TO TENTHS OF A FOOT. _____
12. MULTIPLY STEP 11 TIMES THE NUMBER OF REPETITIONS. _____
    THIS IS THE TOTAL DISTANCE OR D.
13. MULTIPLY STEP 12 TIMES STEP 8 TO GET TOTAL WORK DONE IN POUND-FEET.
    _____
14. IF WE ARE TO COMPARE THE AMOUNT OF WORK WE HAVE DONE WITH THAT WHICH A HORSE COULD DO, WE MUST DIVIDE BY 33,000 POUND-FEET.

H.P. _____ (POUND-FEET) YOUR WORK

33,000 (POUND-FEET/MIN) HORSE'S WORK

15. ANALYSIS: A STRONG STUDENT SHOULD BE ABLE TO DEVELOP UP TO A HALF OF A HORSEPOWER FOR A SHORT TIME. HOWEVER, A HORSE COULD DO THIS EASILY ALL DAY.

16. ASK A FRIEND TO TRY TO MAINTAIN THE MAXIMUM RATE FOR 1, 2, 3, OR EVEN 5 MINUTES. RESULT?

17. IS THERE ANYONE IN CLASS WHO COULD DEVELOP AND MAINTAIN .35 H.P. FOR 2½ HOURS AS DID BRYAN ALLEN IN THE FIRST MAN-POWERED FLIGHT ACROSS THE ENGLISH CHANNEL? IT IS UNLIKELY EVEN IF WE WERE USING LEG MUSCLES INSTEAD OF ARM MUSCLES.

18. REPEAT THE ABOVE USING NEWTONS, METERS, WATTS.

REMEMBER: A. SINCE WE ARE NOT COMPARING OURSELVES WITH HORSES, WE DO NOT DIVIDE BY 33,000.

B. SINCE TIME UNIT IN THE METRIC SYSTEM IS THE SECOND, NOT THE MINUTE, WE MUST DIVIDE BY 60 IN STEP 14 TO GET NEWTON METERS OR JOULES PER SECOND.

STUDENT LABORATORY EXPERIMENT

ALTERNATE: STAIR CLIMB

NAME **DATE** **EXPERIMENT** MECHANICAL POWER

OBJECTIVE:

TO REINFORCE CONCEPT THAT POWER IS A RATE OF DOING WORK.

EQUIPMENT:

MATERIALS/COMPONENTS:

WATCH WITH SECOND HAND
BATHROOM OR WEIGHT ROOM SCALE
TAPE MEASURE
STAIRS

PROCEDURE:

1. DESIGNATE A HELPER TO BE A TIMER.
2. DESIGNATE A HELPER TO COUNT NUMBER OF REPETITIONS (NUMBER OF TIMES STAIRS WERE CLIMBED).
3. ENLIST A FRIEND TO DO THE CLIMBING.
4. MEASURE THE HEIGHT OF STAIRS = _____ (POUND-FEET)
5. WEIGH AND RECORD WEIGHT OF STUDENT WHO WILL DO CLIMBING. _____
6. INSTRUCT STUDENT WHO WILL DO CLIMBING TO CLIMB STAIRS AND RETURN AS MANY TIMES AS POSSIBLE IN 1 MINUTE.
7. BEGIN EXPERIMENT.
8. MULTIPLY HEIGHT OF STAIRS _____ TIMES NUMBER OF REPETITIONS _____ = _____. THIS IS THE TOTAL DISTANCE CLIMBED.
9. MULTIPLY DISTANCE _____ TIMES WEIGHT OF STUDENT _____ = FORCE. THIS PRODUCT = WORK = F X D.
10. IF WE ARE TO COMPARE THE AMOUNT OF WORK WE HAVE DONE WITH THAT WHICH A HORSE COULD DO, WE MUST DIVIDE BY 33,000 POUND-FEET.

$$H.P. = \frac{\text{(POUND-FEET) YOUR WORK}}{\text{(POUND-FEET/MIN) HORSE'S WORK}} = \frac{\text{\_\_\_\_\_}}{33{,}000}$$

11. ANALYSIS: A STRONG STUDENT SHOULD BE ABLE TO DEVELOP OVER A HALF OF A HORSEPOWER FOR A SHORT TIME. HOWEVER, A HORSE COULD COM-

FORTABLY DO THIS ALL DAY.

12. ASK A FRIEND TO TRY TO MAINTAIN THE MAXIMUM RATE FOR 1, 2, 3, OR EVEN 5 MINUTES. RESULT?

13. IS THERE ANYONE IN CLASS WHO COULD DEVELOP AND MAINTAIN .35 H.P. FOR 2½ HOURS AS DID BRYAN ALLEN IN THE FIRST MAN-POWERED FLIGHT ACROSS THE ENGLISH CHANNEL?

14. REPEAT STEPS 4, 6, 7, 8, AND 9 IN NEWTONS, METERS, AND WATTS.

REMEMBER: A. SINCE WE ARE NOT COMPARING OURSELVES WITH HORSES, WE DO NOT DIVIDE BY 33,000.

B. SINCE THE TIME UNIT IN THE METRIC SYSTEM IS THE SECOND, NOT THE MINUTE, WE MUST DIVIDE BY 60 IN STEP 10 TO GET NEWTON METERS OR JOULES PER SECOND.

unit 2
energy/power safty concepts

LECTURE NOTES

IT IS IMPORTANT THAT AN INSTRUCTOR OF AN ENERGY/POWER COURSE REALIZE THAT HIS OR HER RESPONSIBILITY INCLUDES NOT JUST TEACHING SAFETY BUT ALSO THE ESTABLISHMENT AND MAINTENANCE OF A COMPLETE SAFETY PROGRAM. ACCORDING TO THE SAFETY MANUAL FOR NORTH DAKOTA VOCATIONAL EDUCATION (A COPY CAN BE OBTAINED FROM THE RESEARCH COORDINATING UNIT OR THE STATE SUPERVISOR OF INDUSTRIAL ARTS, BISMARCK NORTH DAKOTA.) THE DUTIES OF THE CLASSROOM TEACHER WITH REGARD TO THE SAFETY PROGRAM ARE TO:

1. GIVE INSTRUCTION IN THE SAFE METHODS AND USE OF TOOLS.
2. IMPLEMENT THE SAFETY PROGRAM.
3. MAKE SYSTEMATIC CHECKS OF THE EQUIPMENT TO BE SURE IT IS IN SAFE OPERATING ORDER.
4. MOTIVATE STUDENTS TO STRIVE FOR SAFETY.
5. GIVE WATCHFUL SUPERVISION TO LABORATORY ACTIVITIES.

THE ABOVE STATEMENTS, WHILE EXTREMELY BROAD AND INCLUSIVE DO NOT GIVE SPECIFICS AS TO "HOW TO" ESTABLISH A SAFETY PROGRAM FOR YOUR SITUATION. WHILE THE SAFETY MANUAL GIVES FURTHER SPECIFICS AND IS EXTREMELY VALUABLE AS AN INSTRUCTOR REFERENCE, PERHAPS NO SOURCE OR NO ONE WILL TELL YOU EXACTLY HOW TO ESTABLISH A SAFETY PROGRAM. IN THE END, YOU MUST ASK YOURSELF BECAUSE SOMEDAY A JURY MAY DECIDE WHETHER OR NOT YOUR SAFETY PROGRAM WAS ADEQUATE. THE QUESTION THEY WILL ASK IS: DID YOU ACT AS A REASONABLY PRUDENT PERSON WOULD ACT. OF COURSE, A REASONABLY PRUDENT PERSON WOULD DO EVERYTHING POSSIBLE TO PREVENT ACCIDENTS, INJURIES AND HEALTH HAZARDS WHEREVER MINORS ARE INVOLVED.

THE FOLLOWING POINTS SHOULD PROVIDE FURTHER DIRECTION IN THE SEARCH FOR THE ELEMENTS OF A COMPLETE SAFETY PROGRAM.

1. AS INDICATED ABOVE, THE INSTRUCTOR MUST PROVIDE SAFETY INSTRUCTION. THE KEY ELEMENT HERE HOWEVER, IS THAT THE INSTRUCTION MUST BE <u>ADEQUATE AND CONTINUOUS</u>. IT MUST NOT BE LIMITED TO SAFETY INSTRUCTION AT THE BEGINNING OF THE SEMESTER AND THEN FORGOTTEN. A PRUDENT INSTRUCTOR WILL DOCUMENT THAT HIS OR HER SAFETY INSTRUCTION IS ADEQUATE AND CONTINUOUS. THE METHODS AN INSTRUCTOR MAY USE IN SAFETY INSTRUCTION ARE MANY AND VARIED AND INCLUDE LECTURE, DISCUSSION, TESTS, RELEASE FORMS, DEMONSTRATIONS, AUDIO-VISUALS, AND STUDENT INVOLVEMENT.

2. VISUAL ENVIRONMENT. THE VISUAL ENVIRONMENT CREATED IN THE LABORATORY BY THE INSTRUCTOR IS DOCUMENTATION IN ITSELF. ITEMS THAT SHOULD BE GIVEN ATTENTION IN THIS AREA INCLUDE SAFETY PROCEDURES POSTED ABOVE EACH MACHINE, PROPER FLOOR MARKINGS AND ANTI-SKID STRIPS, USE OF NATIONALLY ACCEPTED COLOR CODES TO DENOTE MOVING PARTS, DANGER AREAS, FIRST AID AREAS, ETC. PROPER DISPLAY AND STORAGE OF PERSONAL SAFETY EQUIPEMNT. MACHINE GUARDS ALWAYS IN PLACE, DISPLAY OF SAFETY CHARTS, SLOGANS, AND SAFETY RECORDS.

3. EQUIPMENT MAINTENANCE. A PRUDENT INSTRUCTOR WILL ESTABLISH AN EQUIPMENT MAINTENANCE SCHEDULE WHICH USES DATED FORMS AND INVOLVES STUDENTS. A FILE SHOULD BE MAINTAINED OF THESE FORMS AND ALL CORRESPONDENCE RELATING TO ATTEMPTS AT REPAIR OF EQUIPMENT. IF THE PERSONS RESPONSIBLE FOR ASSISTING THE INSTRUCTOR IN KEEPING THE EQUIPMENT MAINTAINED ARE UNRESPONSIVE, THE EQUIPMENT SHOULD NOT BE PLACED BACK IN SERVICE.

4. AN INSTRUCTOR SHOULD MAINTAIN A FILE OF ALL RECOMMENDATIONS AND REQUESTS FOR SAFETY IMPROVEMENTS WITH REGARD TO FACILITY AND EQUIPMENT. AN INSTRUCTOR SHOULD NEVER BRING PERSONAL EQUIPMENT TO SCHOOL AS THIS IS THE RESPONSIBILITY OF ADMINISTRATION AND SCHOOL BOARD .

5. EXAMPLE AND LEADERSHIP. THE INSTRUCTOR SHOULD BE AWARE THAT STUDENTS ARE QUICK TO OBSERVE AND POINT UP EVEN MINOR SAFETY VIOLATIONS BY THE INSTRUCTOR. FOR EXAMPLE, THE FAILURE OF THE INSTRUCTOR TO WEAR SAFETY GLASSES FOR EVEN A MOMENT WILL RESULT IN TOTAL DISREGARD FOR THIS SAFETY RULE AND IN THE FUTURE, IF IT IS REPEATED, WILL RESULT IN FAILURE TO OBSERVE OTHER SAFETY RULES.

6. EMERGENCY PROCEDURES. TEACHERS SHOULD REHEARSE WITH STUDENTS PROCEDURES THAT WILL BE FOLLOWED AFTER AN ACCIDENT OCCURS, SINCE PERMANENT INJURY OFTEN IS THE RESULT OF CARE RECEIVED DURING THESE CRITICAL FEW MOMENTS RATHER THAN THE INJURY ITSELF. THIS WILL PREVENT PANIC ON THE PART OF THE STUDENTS AND THE INSTRUCTOR AND INCREASES THE CHANCES THAT PERMANENT INJURY WILL BE PREVENTED. AS A PART OF THIS PROCEDURE EMERGENCY PHONE NUMBERS SHOULD BE CLEARLY POSTED. ALSO EMERGENCY EQUIPMENT SUCH AS FIRE EXTINGUISHERS, FIRE BLANKETS, EYE WASH STATIONS, FIRST AID KITS, ETC. MUST BE MAINTAINED AND KEPT FREE OF CLUTTER. FINALLY, ALL OF THE ABOVE PROCEDURES MUST BE GONE OVER IN ADVANCE WITH SCHOOL ADMINISTRATORS TO ENSURE THAT THE MOST EFFICIENT PLAN OF ACTION HAS BEEN ADOPTED.

7. SUPERVISION. THE ISSUE OF ADEQUATE SUPERVISION CANNOT BE OVER EMPHASIZED. ABSENCE FROM THE CLASSROOM. VISITING WITH FELLOW TEACHERS, DRINKING COFFEE, WORKING ON PERSONAL PROJECTS, PREPARING FOR OTHER CLASSES, ETC., ARE ALL UNACCEPTABLE PRACTICES SHOULD AN ACCIDENT OCCUR. THIS RESPONSIBILITY TAKES ON AN ADDED DIMENSION WITH THE YOUNGER AGE GROUPS.

THE FOLLOWING NOTES AND OVERHEAD TRANSPARANCIES CONCERNING HAZARDS, PREVENTIVE MEASURES, PROTECTIVE MEASURES, CORRECTIVE MEASURES, AS IDENTIFIED BY THE CURRICULUM GUIDE DO NOT IN ANY WAY CONSTITUTE A COMPLETE SAFETY PROGRAM. IT IS INTENDED ONLY TO FOCUS ATTENTION ON THE PECULIAR ASPECTS OF THE ENERGY/POWER LABORATORY.

CURRICULUM GUIDE OUTLINE

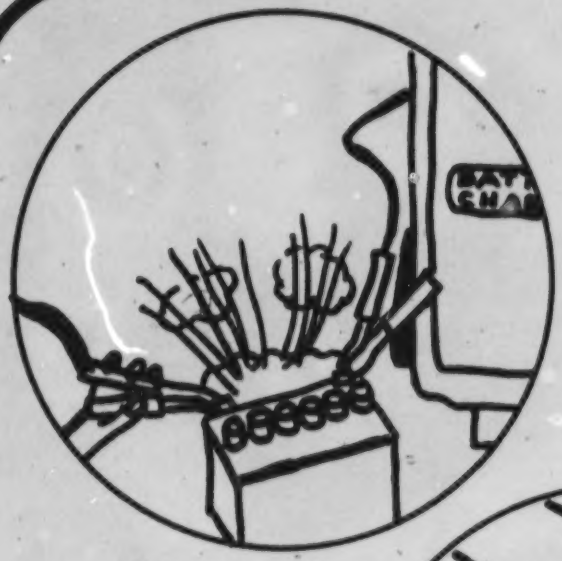
2.00 ENERGY/POWER SAFETY CONCEPTS

- 2.10 HAZARDS
  - 2.11 CHEMICAL
  - 2.12 ELECTRICAL
  - 2.13 MECHANICAL
  - 2.14 RADIATION (LIGHT AND NUCLEAR)
  - 2.15 THERMAL
- 2.20 PREVENTIVE MEASURES
  - 2.21 ATTITUDES
  - 2.22 KNOWLEDGE OF CORRECT USAGE
  - 2.23 EQUIPMENT
  - 2.24 FACILITIES
- 2.30 PROTECTIVE MEASURES
  - 2.31 APPARREL
  - 2.32 CONTAINERING METHODS
  - 2.33 SHIELDING (EYES, FACE, INSULATIVE, ETC.)
  - 2.34 GROUNDING AND OR APPROPRIATE MOUNTING
- 2.40 CORRECTIVE MEASURES
  - 2.41 EXTINGUISHERS
  - 2.42 INHIBITERS
  - 2.43 NEUTRALIZERS

UNIT # 2 TOPIC HAZARDS

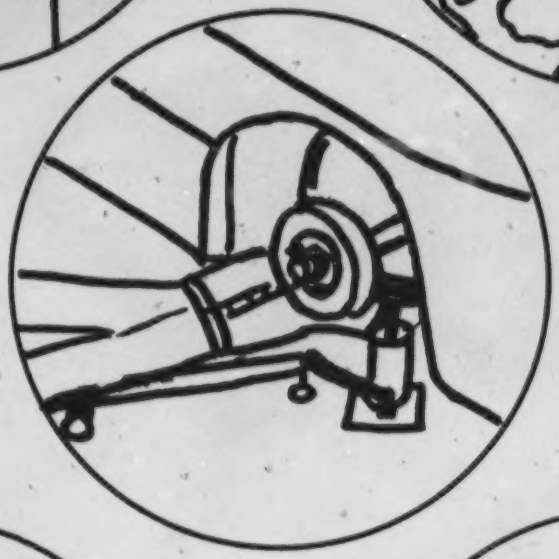
1

VISUAL #



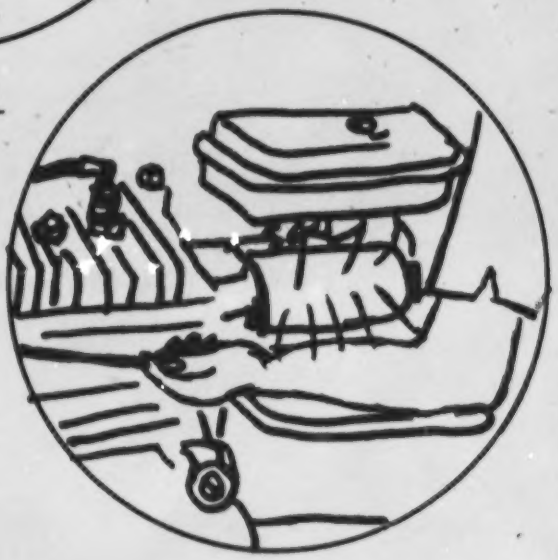
CHEMICAL

ELECTRICAL



MECHANICAL

RADIATION-LIGHT & NUCLEAR



THERMAL

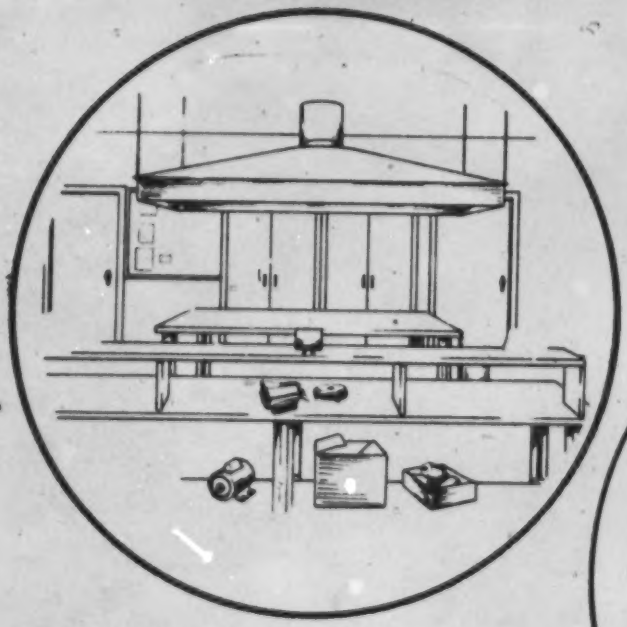
UNIT # 2 TOPIC PREVENTIVE MEASURES

2

VISUAL #

ATTITUDES

CORRECT USAGE OF TOOLS



PROPER FACILITIES AND
GOOD HOUSEKEEPING

PROPER EQUIPMENT; GUARDS AND
STORAGE OF FLAMMABLES

UNIT # 2 TOPIC PROTECTIVE MEASURES

3

VISUAL #

67

Types of Fire Extinguishers

PRESSURIZED WATER

A

SODA-ACID

A

CARBON DIOXIDE

B,C,

DRY CHEMICAL

B,C,D,

FOAM

A,B,

TYPES OF FIRES

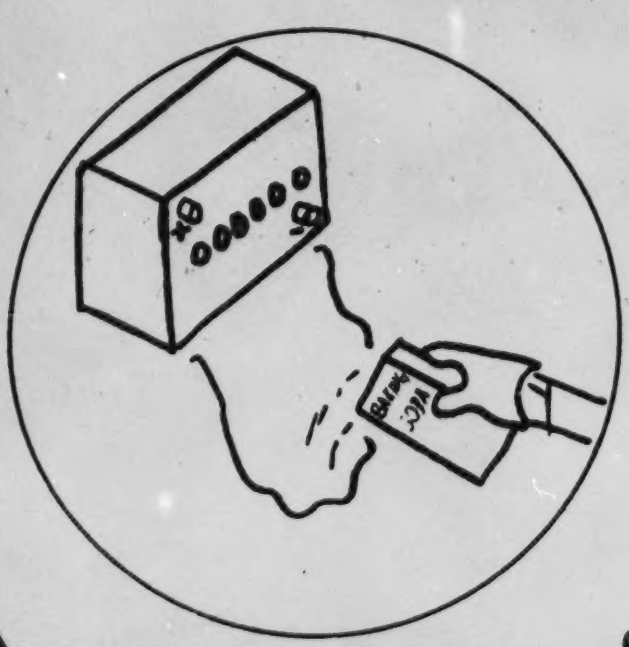
TYPE A, WOOD, RAGS, ORDINARY COMBUSTIBLES

TYPE B, FLAMMABLE LIQUIDS

TYPE C, ELECTRICAL

TYPE D, COMBUSTIBLE METALS SUCH AS MAGNESIUM

WHAT TYPE OR
TYPES ARE NEE
IN ENERGY/POWE
LAB?



NEUTRALIZING SPILLS

CONTAINING AND ABSORBING SPILLS

(check one)
☐ School Jurisdictional
☐ Non School Jurisdictional

RECOMMENDED STANDARD STUDENT ACCIDENT REPORT

(See instructions on reverse side)

(check one)
Recordable ☐
Reportable Only ☐

School District:
City, State:

General

1. Name	2. Address			
3. School	4. Sex Male ☐ Female ☐	5. Age	6. Grade/Special Program	
7. Time Accident Occurred Date:	Day of Week:	Exact Time:	AM ☐ PM ☐	

Injury

8. Nature of Injury

9. Part of Body Injured

10. Degree of Injury (check one)
Death ☐ Permanent ☐ Temporary (lost time) ☐ Non Disabling (no lost time) ☐

11. Days Lost
From School: From Activities Other Than School: Total:

12. Cause of Injury

Accident

13. Accident Jurisdiction (check one)
School: Grounds ☐ Building ☐ To and From ☐ Other Activities Not on School Property ☐
Non-School: Home ☐ Other ☐

14. Location of Accident (be specific)	15. Activity of Person (be specific)
16. Status of Activity	17. Supervision (if yes, give title & name of supervisor) Yes ☐ No ☐
18. Agency Involved	19. Unsafe Act
20. Unsafe Mechanical/Physical Condition	21. Unsafe Personal Factor

22. Corrective Action Taken or Recommended

23. Property Damage
School $ Non-School $ Total $

24. Description (Give a word picture of the accident, explaining who, what, when, why and how)

Signature

25. Date of Report	26. Report Prepared by (signature & title)
27. Principal's Signature	

This form is recommended for securing data for accident prevention and safety education. School districts may reproduce this form adding space for optional data. Reference: *Student Accident Reporting Guidebook*, National Safety Council, 425 N. Michigan Avenue, Chicago, Illinois 60611. 1966. 34 pages.

2 - 8 69

INSTRUCTIONS

Please read carefully — Fill out form completely

Use the form on the reverse side to report each school and each non-school jurisdictional accident. In the upper left corner, check appropriate box:

School Jurisdictional. Any accident which results in any injury to a pupil and/or property damage which occurs in a school building, on school grounds, on the way to or from school, or in connection with any other school-sponsored activity even though not on school property.

Non-School Jurisdictional. An accident which causes restriction of activity to the pupil, occurring anywhere not definitely specified above.

In the upper right corner, check appropriate box:

Recordable. If the accident results in

a. Pupil injuries severe enough to cause the loss of one-half day or more of school time, or

b. Pupil injuries severe enough to cause the loss of one-half day or more of pupil activity during non school time, or

c. Any property damage as a result of a school jurisdictional accident.

Reportable Only. If the accident does *not* cause a *lost time* injury or property damage.

NOTE: Only those forms checked **Recordable** are to be included in the *Annual Student Accident Summary* forms which are submitted to the National Safety Council.

1. Name. Name of injured student.

2. Address. Home address.

3. School. School attended.

4. Sex. Check box.

5. Age. Age of student at last birthday.

6. Grade/Special Program. Grade level such as K—for kindergarten, 1—for first grade, 2—for second grade, etc.; Special Education, Adult Education, Junior College, etc. If a special program, such as Head Start, Student Work Program, Adult Re-Training or Pre-Primary, so indicate.

7. Time Accident Occurred. Indicate the time the accident occurred as follows: Date (month, day of the month, and year); day of the week; the exact time and check AM or PM.

8. Nature of Injury. Indicate, *to the best of your knowledge*, what the injury was, such as burn, fracture, abrasion, etc. If multiple injuries, so indicate and list each.

9. Part of Body Injured. Indicate part of body injured, such as lower left arm, right ankle, scalp, etc. If more than one part of body is injured, indicate as "multiple" and list each part.

10. Degree of Injury. Check one box. If the degree of injury is not immediately known, estimate or use a follow-up system. Reports should not be held up for lack of this information.

Death. If fatal.

Permanent. If injury results in a complete loss of, or loss of use of, a body part or parts, such as the loss of an eye, the loss of use of a limb, amputation of a part of the body, etc.

Temporary (lost time). If the injury does not cause permanent disability, but causes the child to lose one half day or more of school, or one half day or more of normal activity, during a non school period.

Non-Disabling (no lost time). If the injury did not cause permanent disability and/or lost time, or loss of activity.

11. Days Lost. Indicate from one half or more, the number of days that the student was absent from school; and/or the number of days from one-half day or more, the student was restricted from normal activities if during a non school period. One-half day's lost time in school is defined as one-half of the normal school day for that particular student. The time charge for death is 1,200 days. See *Guidebook*, page 24, for permanent disability charges. If lost time is not immediately known, estimate or use a follow-up system. Reports should not be held up for lack of this information.

12. Cause of Injury. Identify the event which resulted in the injury, such as "struck against moving object," "fall from elevation," "rubbed or abraided," "over-exertion," etc.

13. Accident Jurisdiction. Check one box to indicate where the accident occurred.

14. Location of Accident. Indicate exact location of the accident. Example: Second floor corridor near room 210, girls' gymnasium, sidewalk at northeast corner of 12th and Locust, inside stairway at home, etc.

15. Activity of Person. Indicate what person was doing at time of the accident. Example: Conducting a science experiment, playing second base in soft ball, riding as a passenger in parents' car, driving a bicycle, etc.

16. Status of Activity. Indicate status of activity at time of the accident. Example: Regular classroom period, physical education class, intramural athletic practice, interscholastic athletics, recess, lunch period, supervised before or after school activities, at a friend's home, in the kitchen, at a supermarket, etc.

17. Supervision. Check box to indicate whether an adult was present at the scene of the accident; if "yes," indicate by name and title whether this adult was the teacher, another school employee, the parent, another adult, etc.

18. Agency Involved. Indicate the equipment, substance, material, or the thing most closely related to the accident. Example: Glass test tube, motorcycle, ground surface, other person, dog, etc.

19. Unsafe Act. Indicate any act on the part of the person or persons involved which may have caused or contributed to the accident. Example: Using equipment unsafely, feet in aisle, body contact in sports or other action in excess of intent of rule, not following established rules, etc.

20. Unsafe Mechanical/Physical Condition. Indicate any unsafe mechanical or physical conditions such as deep ruts in play area, ice on sidewalk, improperly guarded machine, improperly stored material, poor lighting, porch railing in need of repair, etc.

21. Unsafe Personal Factor. Indicate any unsafe personal factors that may have contributed to the accident. Example: Bodily defects such as defective hearing; lack of knowledge, skill or experience, such as failure to recognize hazards; emotional upsets such as death in the family, new sibling, parental separation or school failure.

22. Corrective Action Taken or Recommended. Indicate what action was taken locally and/or what further action is recommended, if needed action cannot be taken by local school personnel. Example: Maintenance action such as play area holes were filled and leveled; procedural action such as a study is being made to improve the flow of students into the auditorium; engineering recommendation such as the ventilating system should be studied to determine if sufficient for the area involved; curriculum recommendation such as the present course of study for woodworking shop should be reviewed to insure that safe procedures are included; counseling action such as referred child to guidance department.

23. Property Damage. Estimate in dollars the amount of damage, if any, to school property and/or other property as the result of the accident. Do not hold up report for this information. If there was no property damage write "none."

24. Description. Give a *word* picture of the accident, explaining who, what, where, when, why and how of the accident. Include such items as weather, equipment, unsafe conditions, unsafe acts, personal factors, and whether other persons may have contributed to the accident, and how.

25. Date of Report. Date report was completed.

26. Report Prepared by. Signature and title of person preparing report.

27. Principal's Signature.

Eye-Witness Report Form

Name of pupil injured_____ Date_____

Course and room number_____ Time_____

1. What was the nature of the activity engaged in at the time of the accident?
2. What piece of equipment, tool, or material was involved in the accident?
3. Had safety instructions been given the class concerning this?
4. Was another person involved in the accident? If so, in what manner?
5. Where were you in relation to the injured person at the time of the accident? Were you able to see clearly just what happened?
6. Was the injured pupil violating any safety instructions at the time of his injury?
7. In your own words, what person, tool, or circumstance was responsible for this accident?
8. To the best of your knowledge, what was the extent of the injury?
9. What care was given the injured pupil following the accident?
10. Was any personal protective equipment involved in the injury?

_____

Signature of person filling out report

STUDENT SAFETY PLEDGE FORM

_____, WHO IS ENROLLED IN INDUSTRIAL ARTS_____, WILL AS PART OF HIS/HER LAB EXPERIENCE, OPERATE MACHINES, PROVIDING THAT THE PARENT OR GUARDIAN GIVES WRITTEN PERMISSION.

IT IS IMPORTANT THAT EACH STUDENT BE GIVEN PROPER INSTRUCTION, BOTH IN THE USE OF THE EQUIPMENT AND IN CORRECT SAFETY PROCEDURES CONCERNING IT, BEFORE BEING ALLOWED TO OPERATE IT. THE STUDENT MUST ASSUME RESPONSIBILITY FOR FOLLOWING SAFE PRACTICES, AND WE THEREFORE ASK THAT THE STUDENT SUBSCRIBE TO THE FOLLOWING SAFETY PLEDGE.

1. IPROMISE TO FOLLOW ALL SAFETY RULES FOR THE LAB.
2. I PROMISE NEVER TO USE A MACHINE WITHOUT FIRST HAVING PERMISSION FROM THE INSTRUCTOR.
3. I WILL NOT ASK PERMISSION TO USE A PARTICULAR MACHINE UNLESS I HAVE BEEN INSTRUCTED IN ITS USE, AND HAVE MADE 100% ON THE SAFETY TEST FOR THAT MACHINE.
4. I WILL REPORT ANY ACCIDENT OR INJURY TO THE TEACHER IMMEDIATELY.

DATE_____STUDENT SIGNATURE_____

I HEREBY GIVE MY CONSENT TO ALLOW MY SON OR DAUGHTER TO OPERATE ALL MACHINES AND EQUIPMENT NECESSARY IN CARRYING OUT THE REQUIREMENTS OF THE COURSE IN WHICH HE OR SHE IS ENROLLED.

DATE_____PARENT SIGNATURE_____

PARENTS ARE CORDIALLY INVITED TO VISIT THE LAB AND INSPECT THE MACHINES AND TO SEE THEM IN OPERATION.

LECTURE NOTES

POSSIBLE ACTIVITIES:

1. CONTACT THE NORTH DAKOTA SAFETY COUNCIL TO OBTAIN A COPY OF THE DIRECTORY OF AUDIO VISUAL AIDS AVAILABLE ON LOAN. OTHER PUBLICATIONS ARE ALSO AVAILABLE. 515½ EAST BROADWAY, SUITE 102, BISMARCK, ND, 58501. TOLL FREE IN STATE: 800:932:8890.
2. DEVELOP SAFETY RULES FOR ALL MACHINES AND PROCESSES. SEE "SAFETY MANUAL FOR NORTH DAKOTA VOCATIONAL EDUCATION".
3. DEVELOP GENERAL SAFETY RULES FOR THE LAB. UTILIZE STUDENTS.
4. DEVELOP SAFETY TESTS FOR ALL MACHINES.
5. DEVELOP FORMS OR TAGS FOR DEFECTIVE EQUIPMENT. SEE N.D. SAFETY MANUAL OR M.A.V.C.C. PUBLICATIONS.
6. DEVELOP FILE OF SAFETY AND EQUIPMENT MAINTENANCE RECORDS.
7. INVOLVE STUDENTS IN PAINTING MACHINES PROPER COLORS.
8. INVOLVE STUDENTS IN POSTING SAFETY PROCEDURES ABOVE EACH MACHINE.
9. INVOLVE STUDENTS, PRINCIPAL, SUPERINTENDENT, AND SCHOOL NURSE IN DEVELOPING AND REHEARSING PROCEDURES FOR USE SHOULD AN ACCIDENT OCCUR.
10. SPONSOR SAFETY POSTER OR SLOGAN CONTEST.
11. INVOLVE STUDENTS IN SIMULATING POSSIBLE ACCIDENTS ON VARIOUS MACHINES.
12. INVOLVE STUDENTS IN INSPECTING NOT JUST MACHINES, BUT FACILITY REGARDING VENTILATION, LIGHTING, STORAGE, HOUSEKEEPING, EXITS, FIRE EXTINGUISHER LOCATION, ADEQUACY, ETC.

unit 3
energy forms and sources

LECTURE NOTES

UNIT THREE IS TITLED "ENERGY FORMS AND SOURCES." AN EXAMPLE OF THE DISTINCTION BETWEEN THE TWO TERMS IS WIND ENERGY. WIND IS A SOURCE OF ENERGY TO MAN BUT ITS FORM IS MECHANICAL. THE SUN IS A SOURCE OF ENERGY, BUT IS AVAILABLE TO MAN IN THE FORM OF HEAT AND LIGHT. A FURTHER DISTINCTION IS OFTEN MADE THAT PLACES THE SUN AS A DIRECT SOURCE OF ENERGY WHILE THE WIND IS AN INDIRECT SOURCE OF ENERGY BECAUSE THE ENERGY THAT DRIVES THE WIND ORIGINALLY CAME FROM THE SUN. AN EVEN FURTHER DISTINCTION COULD BE MADE, THOUGH SOMEWHAT RIDICULOUS, THAT THE SUN IS AN INDIRECT SOURCE OF ENERGY BECAUSE THE SUN IS FUELED BY A NUCLEAR REACTION.

UNIT THREE IN THIS HANDBOOK IS PRESENTED LARGELY AS INFORMATIONAL CONTENT THOUGH SOME ACTIVITIES WILL BE SUGGESTED, MANY COULD JUST AS EASILY OR APPROPRIATELY FIT IN UNIT FOUR WHICH DEALS WITH NON-CONVERSION OR CONVERSION FROM ONE FORM TO ANOTHER.

THE REASON THAT UNIT THREE IS PRESENTED MOSTLY AS LECTURE NOTES AND OVERHEAD TRANSPARANCY ORIGINALS IS THAT MOST TEXTS IN INDUSTRIAL ARTS FOCUS ON POWER CONVERSION OR "HANDS ON" ACTIVITIES WHILE IGNORING THE THEORY BEHIND THE CONVERSION. HOPEFULLY ENOUGH THEORY WILL BE PROVIDED IN UNIT THREE TO MAKE SUCCEEDING UNITS MORE USEFUL.

MUCH OF THE LECTURE NOTE MATERIAL IS PRESENTED BY USE OF "FACT SHEETS" ORIGINALLY PREPARED BY THE NATIONAL SCIENCE TEACHERS ASSOCIATION UNDER CONTRACT WITH THE DEPARTMENT OF ENERGY. THESE HAVE SINCE BEEN REPRINTED BY SEVERAL GOVERNMENT OFFICES BECAUSE OF THEIR CONDENSED READABLE STYLE.

CURRICULUM GUIDE OUTLINE:

3.00 ENERGY FORMS AND SOURCES
- 3.10 CHEMICAL
  - 3.11 FOSSIL FUELS
    - 3.111 COAL
    - 3.112 OIL
    - 3.113 NATURAL GAS
  - 3.12 BIOFUELS
    - 3.121 BIOMASS (PLANT MATTER)
    - 3.122 AGRICULTURE
    - 3.123 AQUACULTURE
    - 3.124 METHANE
    - 3.125 ALCOHOL
    - 3.126 WOOD

FOR A DISCUSSION OF AT LEAST ONE TYPE OF FOSSIL FUEL, REFER TO FACT SHEET #15 "NEW FUELS FROM COAL." YOU MAY ALSO WISH TO REFER TO UNIT 1, VISUAL #2, P. 1-3.

REFER TO FACT SHEETS #1 AND #2 FOR A DISCUSSION OF SUBTOPIC 3.12 BIOFUELS. VISUAL #1, THIS UNIT WHICH SHOWS SOME COMMON PLANTS THAT SHOW PROMISE IN THE BIOFUELS AREA, MANY OF WHICH ARE GROWN IN NORTH DAKOTA. VISUAL #2 THIS UNIT IS A DIAGRAM OF THE PROCESS WHEREBY CROPS ARE CONVERTED TO ETHANOL WHICH IS MIXED 10 TO 90 TO MAKE GASAHOL.

CURRICULUM GUIDE OUTLINE
- 3.20 ELECTRICAL
  - 3.21 ELECTROSTATIC
    - 3.211 FRICTION
    - 3.212 LIGHTNING
  - 3.22 MAGNETIC

UNIT # # 3 TOPIC 3.10 CHEMICAL

VISUAL # 1

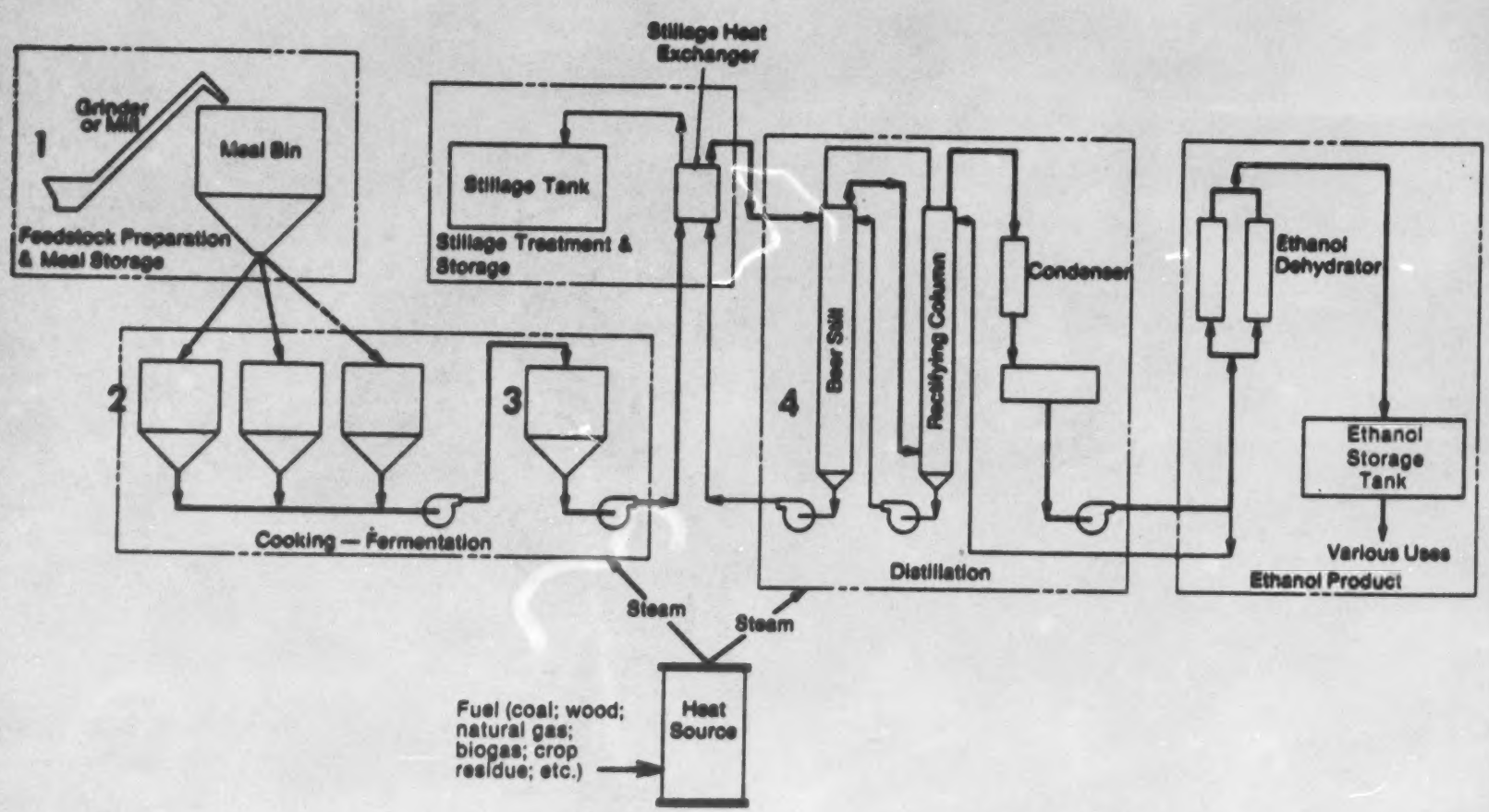
CORN

JERUSALEM ARTICHOKE

SUGAR BEET

POTATOES

WHEAT



77

78

ALCOHOL PRODUCTION

VISUAL # 2

LECTURE NOTES

15. NEW FUELS FROM COAL

FACTSHEET

Office of Education, Business & Labor Affairs

United States Department of Energy

INTRODUCTION

While progress seems to go steadily forward, there are always small cycles of rediscovery and return. The rediscovery of the importance and versatility of coal is such an instance. Coal was the first of the fossil fuels to become industrially important and it is still, on both national and international scales, our most abundant resource. It was realized very early on that useful, clean fuels of many types could be made from it. Kerosene - still called "coal oil" in the rural U.S. - was produced from coal in the mid-19th century, and "town gas" or "water gas" produced from coal provided the fuel for 19th and early 20th century urban lighting and cooking. The discovery of large quantities of easily obtainable oil and natural gas led to the replacement of these coal-based fuels in the 20th century. Germany, forced by the blockade and European geology to find a substitute for oil during World War II, demonstrated on a large scale the technical feasibility of obtaining liquid and gaseous fuel from coal. The return of cheap oil and gas to the marketplace after World War II led again to a general demise in the importance of "King Coal".

A generously funded and determined research and development effort is now underway to produce cost-competitive gaseous and liquid fuels from coal. This resurgence in interest, this time, seems permanent; it is likely to remain as long as coal supplies remain. The new impetus is provided by the realization that the end of the petroleum era is near. National and international oil resources, depleted by the rapidly increasing consumption of the past 50 years, will barely last beyond the turn of the century. In addition, increasing scarcity and the near monopoly enjoyed by the OPEC nations has caused the price of oil products to more than triple over the past five years. Coal and coal-derived fuels can once again compete for the energy dollar.

RESOURCES

Coal is our most abundant resource. In the following table is shown the "ultimately recoverable" resource (the total resource, discovered and potential, which is thought to be economically exploitable with present technology) both in Calories (the scientific term would be kilocalorie),* and in tons, barrels, etc. The coal resource is ten times larger than the others.

The latest data on energy - those for 1975 - show U.S. coal production to have been 646 million tons. At that rate of use, the U.S. coal resources would last about 600 years. The rate of use will increase,

* See the Glossary Fact Sheet, #18, for further discussion and definition.

This material was produced by the National Science Teachers Association under Contract No. EX-76-C-10-3841 with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

of course, especially if new fuels are successfully produced from coal. Even if use increases exponentially by only 2 percent per year, coal will last only 100 to 150 years.

Ultimately Recoverable Resources

Coal	390 billion tons	$2,380 \times 10^{15}$ Cal
Oil	112-189 billion barrels	$168\text{-}284\ 10^{15}$ Cal
Natural Gas	761-1094 trillion cubic feet	$198\text{-}284\ 10^{15}$ Cal

TECHNOLOGY

Coal is almost entirely carbon, containing only small amounts of hydrogen, oxygen, sulfur, and nitrogen. The synthetic fuels must be hydrocarbons - molecules made up of hydrogen and carbon. The basic conversion task, therefore, is to add hydrogen to the carbon atoms.

The numbers give some idea of how much hydrogen is needed. In coal there are sixteen carbon atoms to each hydrogen atom, in heavy fuel oil the carbon to hydrogen ratio is 6 to 1, while in gasoline it is about 1 carbon atom to every 2 or 3 hydrogens, and in natural gas (methane - CH_4) it is 1 to 4. To make any of these fuels from coal, a rather large amount of hydrogen must be supplied.

The four primary ingredients are carbon, hydrogen, oxygen, and heat. Coal supplies the carbon and some of the hydrogen. Additional hydrogen is usually provided either by breaking down natural gas or by reacting coal with steam (H_2O). Oxygen is either supplied in a pure form or as air and the heat is supplied by burning coal or a by-product gas.

The basic chemical reaction for coal gasification is the following:

Coal + water + heat $\longrightarrow$ carbon monoxide + hydrogen

($C + H_2O + \text{heat} \longrightarrow CO + H_2$)

The gas, a mixture of carbon monoxide and hydrogen is combustible but has a low heat value, about one third that of methane. It can be burned on site but long distance pipeline shipping is uneconomical.

To make a natural gas substitute, the "power gas", as this low Btu gas is called, goes through a second "methanation" step in which the carbon monoxide and hydrogen are combined, in the presence of a catalyst* to make methane, the chief component of natural gas.

There is an intermediate step in which the carbon monoxide (CO) reacts with steam to produce carbon dioxide (CO_2) and hydrogen. The CO_2 is then removed and along with it another gas, hydrogen sulfide (H_2S), formed by combining hydrogen with the sulfur impurities in coal. Thus sulfur, the most damaging pollutant in coal, is not present in the gaseous fuel produced from it. Furthermore, the H_2S can be easily converted to elemental sulfur and disposed of or sold.

The steps just outlined are basic to all the various gasification processes. The processes differ in how the heat is obtained and in other details such as whether pure hydrogen and/or oxygen is required, and in operating temperatures and pressures. Brief descriptions of each of the various commercial processes under development are provided in the first reference listed in the bibliography at the end of this Fact Sheet.

Synthetic oils and new solid fuels: There are two other types of fuel being developed from coal -- liquid fuels, and a solid fuel with higher energy content and less sulfur and ash impurities.

The problem of producing a liquid fuel from coal is basically the same one which occurred in gasification. The 16 to 1 ratio of carbon to hydrogen needs to be lowered - at least to the 6 to 1 ratio of fuel oil. There are three basic processes: hydrogenation, the addition of pure hydrogen; pyrolysis, the heating of coal in the absence of oxygen; and catalytic conversions between carbon monoxide and hydrogen.

Hydrogenation produces a heavy fuel oil usable in power plants. Pyrolysis produces three fuels: high Btu or pipeline gas, a synthetic crude oil (syncrude), and char, a carbon residue which itself can be burned (if it does not contain too much sulfur). Hydrogen is added in the hydrogenation process while in the pyrolysis process the coal molecules - which contain some hydrocarbons - are reformed into the hydrocarbon molecules (C_nH_{2n}) and the excess carbon is removed. In the catalytic conversion process the gasifying reaction described earlier takes place producing CO and H_2 and these are combined under pressure and in the presence of a catalyst to make liquid fuels.

The process of producing a solid fuel from coal is called "solvent refining"; the product is "solvent refined coal" (SRC). In the process, crushed coal is mixed with a hydrocarbon solvent - a light oil for instance - at high temperature and pressure. The coal dissolves and the ash and much of the sulfur can then be filtered out. The fuel, which is like solid tar, can be pulverized or heated and melted and thus piped if desired. Its heating value is higher than coal, 32 M Btu per ton vs. about 18 Btu per ton, and of course, it is a much cleaner fuel.

* See Glossary, Fact Sheet #18 for definition

Comparative efficiencies: The range of conversion efficiencies to be expected is shown in the table below.

Summary of Overall Coal Processing Efficiencies

Process	Efficiency (percent)
Solvent refined solids	65 to 70
Liquefaction	62 to 69
Low-Btu gasification	65 to 95
High-Btu gasification	54 to 68

While low Btu gas and solvent refined coal have the highest conversion efficiencies it must be remembered that these fuels will be used, for the most part, in the inefficient (about 30 percent) conversion of heat to electrical energy. Overall, the reliance on coal-based synthetic fuels will lower the efficiency with which we use our primary energy resources. Given the dwindling supplies of oil and natural gas, however, this inefficient use of coal seems necessary.

ECONOMICS

In the previous section we described how we may use our huge coal resource to supplement our dwindling domestic supplies of oil and natural gas. That coal can be used in this way is beyond question. Whether it will be is not so much a question of technology as of economics.

Middle Eastern oil, now selling for about $12 per barrel ($2 per million Btu's), can be produced for about 50¢ a barrel (which is only about 8¢ per million Btu's). We may be able to produce synthetic oil or gas from coal at a cost which will compete with imported oil at present prices. But if OPEC then reduces prices we could be left with expensive white elephants. It is not likely that private companies will make the huge investments these plants will need without some guaranteed minimum price for their product. This country will have to balance its political/security needs against the disadvantages of taking energy prices out of market competition.

Present cost projections leave little room for optimism. In terms of dollars per million Btu's, the synthetic gases are expected to cost about $3.00 and synthetic oils $4.00 to $5.00. These prices are to be compared to $0.50 for regulated and $1.80 for unregulated natural gas and $2.00 to $2.50 for oil.

Although several commercial proposals exist, construction has not yet begun. It is easy to see why. In November 1972, for instance, the El Paso Natural Gas Company estimated the cost of its project as $353 million and the completion date as 1976. In December 1975 the same estimates were $1 billion and 3 to 3 1/2 years. The experience of the other companies has been similar.

The average total assets of the 10 largest gas companies (1974 data) is $2 billion. It is no wonder that they are hesitating to take on projects now running at $1 billion apiece with all the uncertainty we have described. The WESCO group has been quite specific and says it cannot take on a project of this magnitude without "government incentives".

ENVIRONMENTAL PROBLEMS

The most serious problem faced by the synthetic fuel plants, the gasifiers in particular, is their need for water. Not only is water one of the raw materials, providing the hydrogen, but it also carries out its usual cooling role. Water needs will be 1-1/2 to 3 lbs. (or about 2 qts.) for each lb. of coal processed. This is about twice the needs of an electric power plant of the same energy output.

Unfortunately most of the coal which is targeted for gasification is either in the arid Southwest, in the Four Corners area, or in the equally arid North Central region of the Dakotas, Montana, and Wyoming. There will be some hard decisions to be made between agricultural, industrial, and synthetic fuel needs for water in these areas.

A large amount of solid waste will be generated along with the gas. Presumably this will be dumped back in the mine. The air emissions will require both particulate and SO_x removal units since the potential air emissions are large. As we reported earlier, the process itself allows the sulfur to be removed as H_2S.

Land Use: Most of the coal for the gasification plants presently under construction will be strip mined. This is an economic necessity since surface-mined coal is about 20 percent less expensive than deep-mined coal. To provide the tons of coal per day needed by a typical plant from a coal seam 10 feet thick (typical of Southwestern coal deposits) will require the stripping of almost 400 acres per year. The problems associated with strip mining will be aggravated by the fact that irrigation will probably be required for land reclamation in the arid Southwest and North Central coal areas.

Carcinogens: A new and different worry for the synthetic fuel industries has recently surfaced. It has been known for some time that at the high temperatures used in these coal conversion processes, molecules know as "polycyclic aromatic hydrocarbons", PAH, are formed. There is ample evidence that many of these PAH's are carcino-

genic, that is , cancer causing.

The pieces of evidence come not only from observations of workers in coal liquefaction plants, but also from studies of men working in existing coal gasification plants. Coal-produced synthetics seem, from the evidence, to be more dangerous than petroleum products. The same hazard exists for oil distilled from oil shale, a process which also produces PAH's. In one study it was reported that a worker exposed to shale oil was 50 times more likely to get skin cancer than one exposed to oil from a Pennsylvania well. This problem has so far not been publicly addressed by the proponents of a coal-based synthetic fuel industry.

SUMMARY

The technologies for coal gasification, liquefaction, and for producing clean, high Btu solid forms of fuel have been demonstrated in laboratory and small pilot plant processes. These synthetic fuels are not presently economically competitive with other primary energy forms - oil or natural gas in particular.

The Federal Government, if it wishes to assure the development of large scale demonstration plants will, therefore, be forced to depart from its usual role of supporting only research and pilot plant development and underwrite the construction and operation of some large scale demonstration plants.

ERDA funding in Fiscal Year 1977 of the various coal synthetics is expected to be: liquefaction, $73.9 million; high Btu gasification, $45.2 million; low Btu gasification, $33.1 million; demonstration plants, $107.0 million, for a total of $259.2 million. This is about half the level of support for nuclear fission.

The long range goal of the program is to produce 14 of the 180 or so quadrillion (10^{15}) Btu's of energy we are expected to use in the year 2000. It would appear that the abundance of coal and the continuing decline in domestic production of natural liquid and gaseous fuels makes such a goal an obvious one. Whether it is reached, however, will depend on resolution of some difficult environmental problems and on the international economic and political conditions that prevail during the next few years.

REFERENCES

1. Energy From Coal, U.S. Energy Research and Development Administration (Washington: USGPO) May 1976 (ERDA 76-67; $2.05).

2. Energy Alternatives: A Comparative Analysis Chap. 1, The Science and Public Policy Program, University of Oklahoma (Washington: USGPO) May 1975 (Stock No. 041-011-025-4; $7.45).

3. Annual Review of Energy, Vol. 1, Annual Reviews Inc., (Palo Alto, California), 197(see: "Production of High BTU Gas From Coal" pg. 65, "Clean Liquids and Gaseous Fuels From Coal For Electric Fuel", pg. 87.

4. Status and Obstacles to Commercialization of Coal Liquefaction and Gasification, A Report prepared by the General Accounting Office for the National Fuels and Energy Policy Study Committee on Interior and Insular Affairs, U.S. Senate, 94th Congress, Second Session, Serial No. 94-33 (Washingto USGPO) 1976.

5. "Rusty Iron May Be the Key to Cheaper Gas From Coal", Victor D. Chase, Popular Scienc 210; pp. 91-94, January 1977.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation Homes and Buildings
10. Energy Conservation Industry
11. Energy Conservation Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

EDM 1042-15

FACTSHEET

National Science Teachers Association

1. FUELS FROM PLANTS
Bioconversion

John M. and Kathryn Fowler

INTRODUCTION

Stored chemical energy, created in vegetation by photosynthesis, may be a promising supplemental fuel in our energy future. Biomass, plant material in any form from algae to wood, has a remarkably uniform energy content which is about half that of the better coals. A variety of land and water crops which might be easily and economically grown for harvesting and burning as fuel material are presently under investigation. It is estimated that, if an "energy farm" could be designed to usefully convert only 3 percent of the solar energy falling on it, a farm the size of Texas (about 6.5 percent of total U.S. land area) could fuel all the energy needs of the United States in 1985. While there are serious problems associated with large-scale energy farming, even a partial solution could add importantly to our future energy supplies.

The fossil fuels, which are now being depleted, are products of essentially the same chemical process - photosynthesis or "putting together with light". During photosynthesis in plants, light energy is captured and used to convert water and carbon dioxide into oxygen and energy-rich carbohydrates (i.e., molecules containing carbon and hydrogen atoms). This energy is released when the plants or their products decay or are burned. Current efforts are directed at controlling and boosting natural photosynthesis so that crops can be produced which convert sunlight to carbon compounds with high efficiency and produce fuels in a matter of days, instead of the millions of years needed to produce the conventional fossil fuels.

RESOURCES

The idea of growing crops for energy is not new. During the mid 19th century, wood accounted for over 90 percent of the U.S. energy supply. During the fuel shortages of the Second World War, charcoal-fired automobile engines were developed in Western Europe and, in Sweden, large forest areas were cultivated specifically to provide the nation with fuel and fiber. During the Depression of the 1930's, several American studies were conducted on the feasibility of growing grain for conversion to ethyl alcohol which could be used in place of gasoline. Large sugar producing countries, like Brazil, have had some experience with converting a small percentage of their crops and crop wastes to ethyl alcohol for fuel and, in the 1940's, there was considerable interest in the potential of developing trees specifically for fuel. It is only recently, however, with the increased cost of petroleum and the pressures of fuel shortages, that the United States has seriously begun to investigate the potential of "biomass" fuels.

The findings to date demonstrate that a pound of dry plant tissue, when simply harvested and burned, can produce as much as 7,500 Btu's* of heat, a little more than half of the heat available from a similar

* Btu, British Thermal Unit - an engineering unit for energy measurement. See the Glossary Fact Sheet, #18, for further definition.

This material was produced by the National Science Teachers Association under contract with the U.S. Energy Research and Development Administration. The facts, statistics, projections, and conclusions are those of the authors.

amount of coal. With some engineering improvements, a ton of dry biomass can be processed to yield 1.25 barrels of oil, 1,200 cubic feet of medium Btu gas, and 750 pounds of a solid residue that is roughly equivalent to coal in heat value.

The total U.S. resource base, the amount of biomass grown in the U.S. land area per year, is estimated at 5 billion tons. The energy value of this total (at 7,500 Btu's per pound of dry biomass) is 75 Q Btu, a little more than the total U.S. energy consumption in 1975.

TECHNOLOGY

One of the major problems in growing plants for energy is that photosynthesis is a relatively inefficient process, seldom exceeding 3 percent efficiency during the growing season. This means that 97 percent of the solar energy falling on the plant is not converted into stored energy, but is reflected away or dissipated into the atmosphere. In fact, a year-round average of just over one percent efficiency is typical for most high-yield crops, so that it requires a large amount of land to produce a given energy output. Based on yields of 10 to 30 tons of biomass per acre per year, the land required for a 100 Mw organic-fired plant (small by today's standards) would be at least 16,000 acres, and it could be twice that. By comparison, a 1000 Mw coal-fired power plant -- ten times the generating capacity--requires, on the average, about 200 acres of strip-mining per year, or a total of 6000 acres over the same 30 year period.

The major research interest in bioconversion technology is in increasing plant biomass, producing a maximum amount of plant tissue with a minimum investment in time and money. The development of better energy crops will depend upon improvements in agriculture and silviculture*(the development and care of forests).

While many of the basic farming processes have remained unchanged for centuries, farm production methods have changed drastically. Farm productivity has tripled in the last forty years and it has been estimated that man-hour productivity has increased seven-fold, mostly as the result of improved (hybridized) crops and new farm machinery. One problem with this increased productivity, however, has been that it has come at the cost of increased use of petroleum, for fertilizer and for fuel in farm machinery. (Modern U.S. agriculture, as an industry, is the nation's largest consumer of petroleum; energy for food production required 40 percent of the total U.S. industrial energy consumption in 1973.)

It is these production improvements, however, which make the possibility of large-scale energy farming feasible. Current efforts are focused on developing a plant which will combine large biomass with the ability to conserve water and nutrients. Under current technology, for instance, an acre of corn will produce about 6 tons of dry organic material. By comparison, certain plants, such as Eucalyptus trees, have biomass yields on the order of 8 to 25 tons per acre. Other large yield crops which were noted in a recent University of Oklahoma study* include: sugar cane (12 to 50 tons), sorghum (8 to 30 tons), algae (15 to 30 tons), and sunflower (10 to 20 tons). It is hoped that the large biomass yield characteristic of these plants can be extended to other crops through techniques such as hybridization.

ENERGY FARMS IN PRACTICE

The search for an agricultural crop with large biomass and high solar conversion efficiency has led to the investigation of a wide variety of land and water crops. Probably the most familiar fresh-water energy crop currently under study is algae, the green or blue-green, single-cell water plant which is found in profusion around the world. Pilot plants for algae cultivation have been constructed in which special nutrient culture mediums are kept in circulation by a complex system of circulating pumps and heat exchangers. These have proven to be very expensive, however, mostly due to the problem of harvesting and dewatering the crop. It may well be that algae, which has a very high protein content, will prove to be better suited as a food crop.

Similar production problems are affecting the development of water hyacinths as a fuel, even though these rapidly-growing, nutrient-rich water plants have a productivity of up to 85 tons of dry matter per acre per year. There has been some success with growing both algae and water hyacinths in sewage treatment waters.

The experiments (conducted by NASA) in which water hyacinths are grown in sewage water are particularly interesting. One acre of sewage can produce enough nutrients to produce 800 to 1600 lbs of dry water hyacinths per day. This amount pf plant material can be used to generate 3,500 to 7,000 ft^3 of methane gas (along with half a ton of fertilizer). What is of even greater interest, however, is that this energy production is a by-product of growing these plants in sewage. The primary goal is to clean up the water by absorbing the sewage nutrients and chemicals in the plant.

* "Energy Alternatives, A Comparative Analysis", The Science and Public Policy Program, University of Oklahoma (Washington:USGPO)May 1975.

Water hyacinth growth in Southern waterways is an expensive nuisance. In Louisiana there are an estimated 1 million acres of waterways infested and another 100,000 acres in Florida. Over 1 billion ft^3 of methane per day could be harvested from Louisiana's water hyacinths alone. It is, of course, the cost of harvesting these crops that has so far reduced the commercial attractiveness, but the need to open up the waterways, the water purification potential, plus the energy yield may cause interest in this process to mature.

Other promising biomass schemes are those which call for the cultivation of land perennials, such as eucalyptus and sycamores, and of large marine algae, such as the giant sea kelp. Kelp farming is currently being studied on open-ocean rafts at San Diego, California where large brown kelp is being grown for conversion to methane. Assuming success of this program, capturing the solar energy which falls on a square of ocean area about 470 miles on each side would produce enough kelp to make 23 trillion cubic feet of gas each year. This is about equal to the nation's total 1975 natural gas demands. Kelp is a particularly attractive crop: it is fast growing, occupies inexpensive space, does not require irrigation, and offers the additional benefit of enhancing the local fish crop.

There is also significant interest in using trees for fuel. There are presently 250 million acres of forest land not devoted to commercial timber production (another 500 million acres are used commercially). If 100 million acres of this non-commercial land were used to produce wood fuel at a conservative 6000 lb. per acre, the energy equivalent of 900 million barrels of oil could be obtained (at 100 percent conversion efficiency). This is about 15 percent of our current oil consumption. Certain species could produce much more than 6000 lbs per acre. Eucalyptus trees, which grow in frost free regions, have attractive characteristics and are currently being grown as paper pulp stock, so that the technology for their cultivation and harvesting is fairly well known.

Currently, large-scale tree farming efforts are being focused on a scheme devised by Dr. George Szego, a prominent energy specialist. Szego has proposed growing trees as fuel for a conventional steam electric power plant. He estimates that, under good conditions, trees could convert sunlight to wood at about 3 percent efficiency and this wood could be burned in a conventional power plant at about 40 percent efficiency. This would mean that a 1000 Mw plant would require about 112 to 630 square miles of woodland, depending on growing conditions. Ideally, the trees would be harvested every ten years and burned in a power plant located at the center of the tree farm, thereby minimizing transportation costs. Under these conditions, Szego estimates that costs would range from $.30 to $.45 per million Btu's. This compares to current prices of $.75 per million Btu's for coal and $2.00 per million Btu's for oil. There is, however, some skepticism about this scheme, particularly in the forest industry.

While tree farms would not likely compete for good agricultural land, they would probably compete with land currently used by the forest industry to meet the world's growing appetite for paper products, a demand that is projected to double in the next 25 years. It is pointed out, however, that under current practice, 50 to 90 percent of plants and trees are wasted in industrial husbandry operations and that ashes from the burned wood could be returned to the soil as an efficient means of replacing the soil's minerals. As it is, wood, bark, waste liquor from paper mills, sawdust, and mill wastes are all currently used in the lumber and paper industries as sources of process heat. In fact, the U.S. presently obtains 1-2 percent of its total energy consumption from wood. By comparison, Sweden obtains 8 percent of its energy from wood, Finland obtains 15 percent, and Brazil obtains about 27 percent.

Several interesting methods of converting wood biomass to fuels are currently under study, including refinements of the wood (or charcoal) gasifiers which were widely used during the Second World War to power trucks and cars. A company in New Hampshire has developed a unit which converts about 150 pounds of wood waste per hour to a gas which is burned directly in oil or gas fired boilers. Similar processes are being developed at Georgia Tech where the oil and charcoal are made into a liquid fuel for burning in industrial boilers.

There is also growing interest in the possibility of converting agricultural crops to intermediate fuels, such as alcohol, which can be distilled from grain. The National Petroleum Council has estimated that such a process could be competitive with coal if crops were grown specifically for fuel at a production rate of 20 tons of dry matter per acre. Costs for a fuel crop comparable in energy value to coal would be about $10.00 per ton, as compared to $17.00 per ton for coal. Some attention is also being directed to the possibility of capturing the hydrogen in plant material for use as a fuel, but this is an idea which is still in its infancy.

In another direction, there is discussion of the attractiveness of rubber plants as an energy crop. The sap of this plant is already a hydrocarbon and could perhaps replace the petrochemicals in many synthetic substances. An ideal plant

of this type may in fact be the guayule which can grow on the marginal desert areas of the Southwest and for which there was considerable enthusiasm during the wartime rubber shortages. The fact that it does not compete with food crops for land will be in its favor.

SUMMARY

The relative abundance of arable land in the United States, the easy convertability of biomass into desirable liquid and gaseous fuels, and the low environmental impact of either the production or combustion of these fuels (organic materials are generally low in sulfur, for instance) have all served to stimulate interest in growing plants for energy.

The strongest argument against the "plants for energy" idea is based on competition for the land. With the growing food shortages, land that can meet the nutrient and water requirements for energy farming might be better utilized for food crops. Biomass cultivation also suffers in a direct comparison with, for instance, solar collection schemes using solar cells for thermal collectors where efficiencies of 10 to 20 percent could be attained instead of the 1 to 3 percent photosynthetic efficiency. In the spirit of "if you can't beat them, join them", the biomass enthusiasts point out that these schemes are not mutually exclusive. Land can produce food and leftover biomass. The rubber producing guayule may grow under and around the rows of solar collectors.

As with other solar technologies, the Federal support for research and development in biomass conversion is growing, from $1 million in 1975 to $3.8 million in 1976, to an authorized $6 million in 1977. The ERDA projection is for about 10 Q Btu of energy from biomass sources (other than waste recovery) by 2000 -- 5 to 6 percent of the total projected energy use that year.

To date, no bioconversion system has been demonstrated to be cost competitive with conventional fuels and it may be that energy farming will develop environmental problems which will offset much of its current appeal. Little is known, for instance, about the long-term effects of large-scale, single-crop farming (monoculture), but there is evidence that there are inherent problems, in such a system, with insect and disease epidemics. For the present, bioconversion of agricultural crops into fuel remains an exciting, if unproven, alternative to conventional fuels and power plants. Increasingly, however, attention is being focused on a related bioconversion scheme, the use of organic waste as fuel, and it may be that large-scale future efforts will be focused in that direction. It is discussed in Fact Sheet #2.

REFERENCES

1. Capturing the Sun Through Bioconversion; Proceedings of a Conference, March 10-12, 1976, Washington, D.C. (Washington: Center for Metropolitan Studies) 1976.

2. "Solar Bioconversion" (pp. 441-452) in Energy for Survival, Wilson Clark (Garden City: Doubleday) 1974.

3. "Organic Farms" (pp. 11-19 to 11-25) in Energy Alternatives: A Comparative Analysis, the Science and Public Policy Program, University of Oklahoma (Washington: USGPO) May 1975 (Stock No. 041-011-0025-4; $7.45).

4. "Renewable Clean Fuel Sources" (pp. 22-29) in Solar Energy as a National Energy Resource, NSF/NASA Solar Energy Panel (Washington: USGPO) December 1972 (Stock No. 3800-00164; $1.20).

5. "The Flow of Energy in the Biosphere," David M. Gates Scientific American (September 1971 Special Issue).

6. "More Energy from Photosynthesis" (pp. 206-208) in Energy-Environment Source Book, John M. Fowler (Washington: NSTA) 1975 (Stock No. 471-14692; $4.00).

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from: ERDA-Technical Information Center P.O. Box 62, Oak Ridge, TN 37830

FACTSHEET

National Science Teachers Association

2. FUELS FROM WASTES
Bioconversion

John M. Fowler

INTRODUCTION

Driven by the twin scarcities of inexpensive disposal sites and cheap energy, this country is becoming increasingly aware of "Trash Power". In 1973, we had to dispose of 135 million tons of municipal solid waste--3.5 lbs. of waste per person, per day. The cost of collecting and disposing of this urban waste was about $3.5 billion and this bill is steadily increasing as landfill and ocean disposal sites disappear and the cost of environmental protection is added to disposal techniques. EPA projects collection, processing and disposal costs to increase from $26 per ton (1964) to $50 per ton in 1985.

At the same time that the economic liability of this organic waste material is increasing, its potential value as an energy source is also increasing. Municipal solid waste is about 80 percent combustible. The energy potential of these 135 million tons is equivalent to 150 million barrels of oil per year, or $1.8 billion at its energy equivalance in $12 per barrel of oil.

These data consider only the municipal waste. In addition to this, we produce each year even greater amounts of agricultural and lumbering residues which are also combustible.

Reclaiming energy from waste is not a completely new idea. Trash is burned to produce process steam and steam heat for buildings in many European cities. Two U.S. cities are currently testing the feasibility of a technique in which urban wastes are burned with coal in a conventional power plant. In the more sophisticated systems that are also being tried out, waste materials are converted to intermediate fuels such as oil or methane (the major component of natural gas).

RESOURCES

If we add to the urban waste, the municipal sewage sludge that must be disposed of, industrial waste, and agricultural and forestry residues, the total annual waste/fuel stockpile (according to 1971 data) is about 1000 billion tons. This total cannot, of course, all be considered as potential fuel. Some of it is inorganic and won't burn, much of it is too widely scattered to be worth collecting.

It is mainly the organic wastes that are of interest from an energy point of view, once-living material whose molecules contain energy that can be released. The inorganic components are minerals (iron, tin, etc.) or glass and either contribute only to the ashes or, in sophisticated waste disposal systems, can be recycled. (This recycling, of course, saves energy. Recycling a pound of aluminum, for example, uses only 5 percent as much energy as would be required to produce it from the raw ore.)

This material was produced by the National Teachers Association under contract with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

We summarize in the table below, the quantities of organic waste and residues available from different sources.

Amounts of Organic Waste (and Residues) by Source

Dry Weight in Millions of Tons

Source	Readily Collectible	1971 Total Amount Generated	1980 Total Amount Expected
Urban refuse	55.0	100	222
Manure	26.0	200	266
Logging & wood manufacturing	5.0	55	59
Agricultural crops & food wastes	12.3	390	390
Industrial wastes	5.2	44	50
Municipal sewage solids	1.5	12	14
Miscellaneous	5.0	50	60
	220.7	851	1,061

We have used the terms "waste" and "residue" and some distinctions can be made between them. Waste has a negative connotation, it has to be disposed of and its collection and disposal usually costs us something. Crop and forestry residues, however, have some positive value. Some of them have commercial value (sawdust, corn cobs, etc.) and most of them produce benefits when returned to the soil. If we choose to convert them to energy there will be some replacement costs to consider.

Considered as a net energy source, however, the "readily collectable" organic wastes in this 1971 tabulation is impressive. At a conversion ratio of 9 million Btu* per ton, the "readily collectable" 220.7 million tons of organic material could have produced about 2 Q Btu (Q=quadrillion or 10^{15}) which is nearly 3 percent of the energy we used in 1975.

The composition of the organic fraction of municipal waste is important. About half of it is paper, 5 percent plastic, 5 percent wood, and 17 percent is food wastes. Paper poses somewhat of a dilemma. Although it makes up only half the weight, it provides more than two-thirds of the total heat value. We would, in the long run save more energy by recycling the paper, but removing it from the trash will lower the heat value of the remaining material.

This dilemma introduces a broader consideration that should color all of our thoughts about energy waste. That these organic wastes represent such an impressive resource stems from the fact that we generate an impressive amount of them. We can reclaim energy from this scrap pile by the various conversion processes described below and by other recycling techniques. We could save more energy, however, by conservation practiced at the source, by using less paper and plastic in packaging, for instance, or getting more use from fabrics and furniture. The harsh Second Law of Thermodynamics assures us that we can never recover all the energy that went into the manufacture of the materials which end up as trash.

TECHNOLOGY

There are two general approaches by which we can convert organic wastes to energy: thermal systems (burning or converting to a fuel by some heat demanding process) and biological systems. We describe below the most important of the several different approaches.

Thermal Systems: The major techniques within this category are direct (or mass burning), pyrolysis, and hydrogenation. Of these approaches, direct burning appears to be the cheapest and quickest way for a community to utilize its wastes for power generation. The wastes are prepared by shredding and sorting (to remove valuable metals and noncombustible materials), and then burned with the plant fuel, usually coal. In addition to its use as a supplementary fuel in coal-fired furnaces, steam can be generated (and then distributed) as an auxiliary output from a more conventional incinerator. This practice has a long history in Europe.

Pyrolysis is the chemical decomposition of waste in the absence of oxygen. Materials are heated in the absence of air at atmosphere pressure, and several products are produced: low Btu gas, char (partially burned carbon residue), and a heavy tar-like oil. All three of these products can be used as fuels. The oil, however, has a high viscosity (it must be hot to flow easily), and a lower Btu value than ordinary fuel oil (10,500 Btu/lb vs. 18,200 Btu/lb No. 6 fuel oil). It will only be an attractive fuel to power plants.

Hydrogenation is the addition of hydrogen to an organic molecule to increase the ratio of hydrogen to carbon as is necessary for the production of gaseous or liquid fuels. It is a process used for the production of oil or gas from coal (see Fact Sheet #15), but it has also been successfully used in the laboratory to make these fuels from the organic waste.

Biological Systems: Most of the biological

*A Btu, British Thermal Unit, is a unit of energy. By comparison, a ton of coal contains about 25 million Btu. For definitions of these and other items, see the Glossary, Fact Sheet #18.

systems use anaerobic digestion; the bacterial digestion of organic materials in the absence of oxygen. From experiments, it appears that a pound of dry organic solids can produce 3 to 5 cubic feet of gas with a 55 percent methane content. The residual sludge can also be dried and burned, increasing the energy output.

Methane production plants have been built both for municipal sewage sludge and for animal manure at some feedlot operations. Another and cruder method under investigation at Los Angeles is to tap the methane produced by anaerobic processes in landfills (the cover of soil keeps out the air). One fill being investigated there contains 6 billion tons of material and will produce, it is hoped, 600 million cubic feet of 550 Btu per ft^3 gas per year over a 70 year period. The gas will be purchased by the Pacific Gas and Electric Company.

It is also feasible to produce glucose (sugar) from the cellulose component (of wood and paper) and then to ferment the sugar to alcohol which is a high quality fuel capable of being used alone or blended with gasoline. This conversion may turn out to be of particular importance for some of the agricultural and forestry residues.

WASTE CONVERSION IN PRACTICE

One of the most convincing U.S. experiments was begun in 1970, with EPA funding, at Union Electric Company's Merrimac Power Station in St. Louis, Missouri. Commercial and residential waste was shredded, separated to recover ferrous metals, and the organic fraction was burned to supplement coal in a pulverized coal-fired furnace, accounting for as much as 20 percent of the total heat energy at maximum use. The initial experiment was apparently a success. Union Electric has plans to set up a subsidiary, Union Colliery Company, to design, build, and manage a system that will process 8000 tons per day of raw solid waste, separate and recover the metal and sell the fuel to the parent company for use as a coal supplement.

There is a similar operation beginning in Ames, Iowa with a 200 ton per day capacity. Monroe County, New York has begun to design a 2000 ton per day plant and New York City has started several design studies for similar operations.

Several American companies have also invested substantial capital in pyrolysis systems. Three of these companies, Occidental Petroleum, Union Carbide, and Monsanto are experimenting with what they call "total resource recovery systems", in which all of the salable materials including combustion products, are collected for future use.

The city of Baltimore, Maryland in conjunction with State and Federal agencies, constructed a LANDGARD system (developed by Monsanto) designed to handle 1000 tons of solid waste per day and from this produce a low Btu gas plus 80 tons of char, 70 tons of ferrous metals, and 170 tons of glass. The gas is burned to produce 4.8 million pounds per day of steam, which will be piped one mile to a Baltimore Gas and Electric Company plant. The Baltimore plant, however, is experiencing severe start-up problems and is showing how difficult it is to go from small scale demonstration to large scale operation.

In the Occidental Petroleum process, an oil (called Garboil), which can be used as a power plant fuel, is the principal product. A 200 ton per day plant is being built in California to process waste from Escondido and San Marcos, California. From a ton of waste, a barrel of oil and 160 lbs of char is produced and 140 lbs of metal and 120 lbs of glass recovered. The Union Carbide "PURDX" process produces a medium Btu gas which is both valuable as a fuel and may, in the future, be useful as a chemical raw material.

The production of methane from sewage has a considerable history in this country--New York City has used this process for 30 years. Broader use for fuel production, using sewage or agricultural residues, is in an earlier stage in this country. Both India and China, however, use methane digesters as important components of their decentralized energy programs. There are half a million small home and farm units reported in China, India is installing 100,000 such units and Korea 50,000.

ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS

While some of the techniques we have described may produce a fuel which is economically competitive, most of them need credit for solid waste disposal to be economically viable. The recycling of metal and similar usable waste products will also be counted on the credit side. Garbage disposal costs range from $3 to $5 per ton, when landfills are used, and up to $20 per ton for incineration and similar expensive techniques. As inexpensive landfill sites become rare, not only does the disposal cost rise, but so do the transportation costs.

There will be some environmental problems, no doubt, but these appear to be manageable. Organic waste is typically low in sulfur, reducing that problem. Nitrous oxides will be produced, as always, when combustion occurs in the air, and there will be particulate matter requiring removal, but the ash problem is much less than that with coal. There will be

sludge to dispose of and water to purify, but viewed against our present waste problems, these problems do not loom large.

If we consider large scale energy conversion of agricultural and crop residue, some balance will need to be struck between energy needs and the needs of the soil. Manure and crop residues may, for instance, return more value if put back into the soil to replace fertilizer (which has dollar and energy value) and to maintain proper soil texture. In the end, these decisions are economic. The residues--forest or agricultural--belong to the producer and he will give them away, sell them or use them in the manner which brings him the most economic benefit. It will probably be left to society to provide for the necessary long term protection of the soil.

SUMMARY

Organic wastes represent an important supplementary fuel source for the future. The total potential resource is large. If all the 1971 waste had been converted to energy it would have satisfied 13% of the total energy demand and 44% of the total electrical demand. The amount that can be economically converted is considerably smaller, however, and would provide only 1 to 3 percent of the total energy.

Conversion plants will need pollution control devices, but generally their contribution to pollution would be lower than the fossil fuels. Furthermore, the conversion of waste would significantly reduce the serious disposal problems which already exist.

In the enthusiasm for trash-to-energy conversion, however, one should not forget that the trash, the raw material, is waste. While these conversion techniques described do reclaim some of its energy potential, greater gains can be achieved by avoiding its creation in the first place. A styrofoam cup reused, for instance, saves more energy than can be obtained by burning it for fuel if the energy cost of replacing it is considered. The combination of reducing the amount of waste and waste conversion, however, offers important future energy savings.

REFERENCES

1. Capturing the Sun Through Bioconversion, Proceedings of a conference held March 10-12, 1976, Washington, D.C. (Washington: Washington Center for Metropolitan Studies, 1717 Massachusetts Avenue, N.W., Washington, D.C. 20036), 1976.

2. Blum, S.C., "Tapping Resources in Municipal Solid Waste", Science, 191: 669-679, February 20, 1976.

3. Report prepared by the Science and Public Policy Program, University of Oklahoma, "The Organic Waste Resource System". USGPO, Washington, D.C., May 1975. (USGPO Stock No. 041-0011-00025-4; $7.45), pp. 10-1 to 10-19.

4. Clark, Wilson, "The Chimerical Promise of Solar Bioconversion". In Energy for Survival. Anchor Press, N.Y., 1974, pp. 441-467.

5. Bureau of Mines Circular No. 8549, "Energy Potential from Organic Wastes: A Review of the Quantities and Sources", U.S. Bureau of Mines, Washington, D.C., 1972.

6. "Waste Materials", Clarence G. Golueke and P.H. McGauhey in Annual Review of Energy, Volume 1, Jack M. Hollander, Editor (Palo Alto, California: Annual Reviews, Inc., 4139 El Camino Way, Palo Alto, California 94306), 1976.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

LECTURE NOTES

ELECTRICAL ENERGY IS NOT USEABLE TO MAN DIRECTLY. THIS IS NOT TO SAY THAT LIGHTNING FOR EXAMPLE IS UNIMPORTANT IN THE BALANCE OF NATURE, INDEED LIGHTNING MAY HAVE BEEN ESSENTIAL IN THE DEVELOPMENT OF LIFE ITSELF.

GENERALLY WE MUST PRODUCE ELECTRICAL ENERGY BY CONVERTING IT FROM SOME OTHER FORM. IN VISUAL #3 WE SEE MUSCLE POWER BEING USED TO PRODUCE ELECTRIC ENERGY BY USE OF THE MAGNETIC FORCE AND THE ELECTRIC FORCE. THESE TWO DISTINCT YET RELATED FORCES CAN BE DEMONSTRATED EASILY IN THE CLASSROOM.

THE MAGNETIC FORCE IS THE RESULT OF THE SPIN OF THE ELECTRONS. THIS IS NOT OBVIOUS IN MOST MATERIALS BECAUSE ELECTRONS PAIR OFF AND DEVELOP OPPOSITE SPINS WHICH CANCELEACH OTHERS TORQUE EFFECT SIMILIAR TO COUNTER-ROTATING PROPELLERS IN SOME TWIN ENGINE AIRPLANES. INSOME MATERIALS, SUCH AS NATURAL MAGNETS, THIS PAIRING OFF DOES NOT OCCUR AND ALL ELECTRONS CAN BE FORCED TO SPIN IN THE SAME DIRECTION BY A MAGNETIZING FORCE SUCH AS THE EARTHS MAGNETIC FIELD. WHEN MOST ELECTRONS ARE SPINNING IN THE SAME DIRECTION THEIR TORQUE EFFECTS ADD TOGETHER TO PRODUCE A LARGE EXTERNAL FORCE - THAT OF A MAGNET. WHEN A CONDUCTOR IS FORCED THROUGH THIS FIELD USING MUSCLE POWER, THE ELECTRONS IN THE CONDUCTOR ARE FORCED TO SPIN THE SAME WAY AND PRODUCE A CURRENT. MOST COMMERCIALLY AVAILABLE POWER IS PRODUCED THIS WAY.

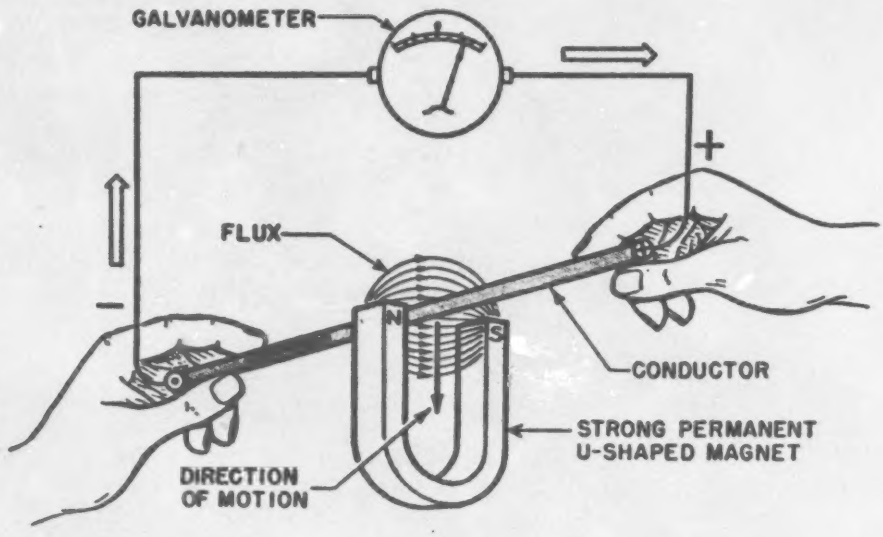
THE ELECTRIC FORCE IS A RESULT OF THE ATTRACTION OF ELECTRONS AND PROTONS. THIS FORCE IS SIMILIAR TO THE ATTRACTION BETWEEN THE EARTH AND US - GRAVITY. THE MAJOR DIFFERENCE IS THAT ELECTRONS ALSO REPEL ELECTRONS AND PROTONS REPEL PROTONS. STATIC ELECTRICITY CAN BE PRODUCED BY MUSCLE POWER AND FRICTION. THE ELECTRO-STATIC FORCE AND STATIC ELECTRICITY IS NOT RESPONSIBLE FOR COMMERCIALLY AVAILABLE ELECTRIC POWER BUT IN RECENT YEARS HAS FOUND WIDE USE IN INDUSTRY.

CURRICULUM GUIDE OUTLINE:

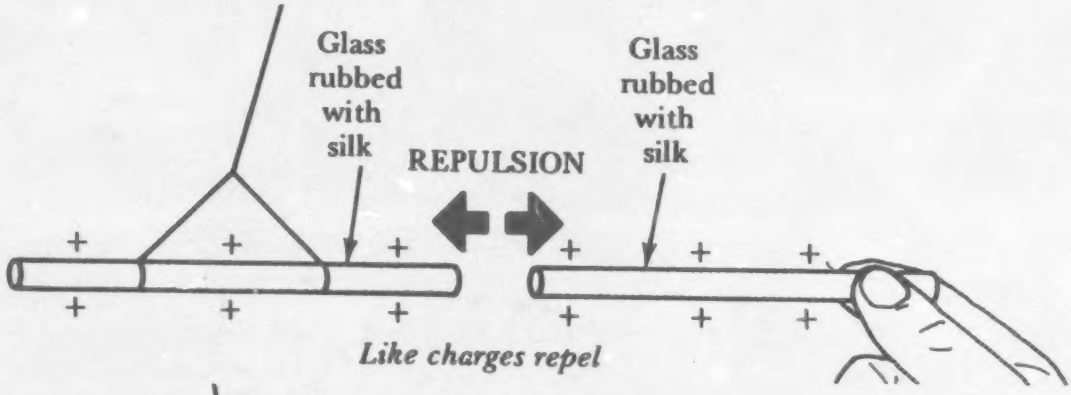
- 3.30 LIGHT
  - 3.31 SOLAR
    - 3.311 HELIOCHEMICAL (PHOTOSYNTHESIS)
    - 3.312 HELIOELECTRICAL (SOLAR CELLS, ETC.)
    - 3.313 HELIOTHERMAL (SOLAR COLLECTORS)
  - 3.32 RADIOACTIVE

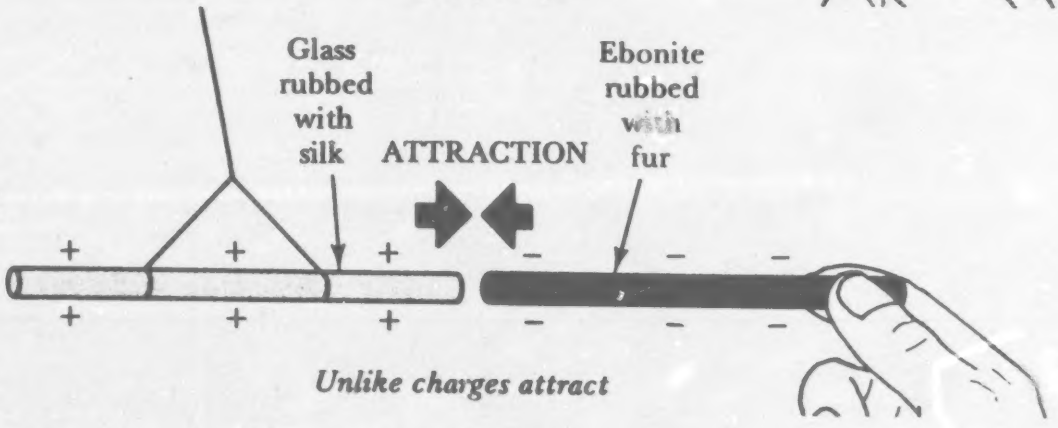
LIGHT COMES TO MAN IN A DIRECTLY USEABLE FORM, THAT IS, IT IS NECESSARY FOR HEALTH, VISION AND WARMTH. IT IS ALSO CONVERTED IN VARIOUS WAYS TO DIFFERENT FORMS AND IS STORED FOR USE WHEN THE SUN IS NOT SHINING. THREE MAJOR METHODS OF CONVERSION AND STORAGE ARE LISTED ABOVE IN THE CURRICULUM GUIDE OUTLINE AND ARE SHOWN IN VISUAL #4.

REFER TO FACT SHEET #4, #5, AND #7 FOR INFORMATION.



ENERGY PRODUCED AS A RESULT OF THE MAGNETIC FORCE

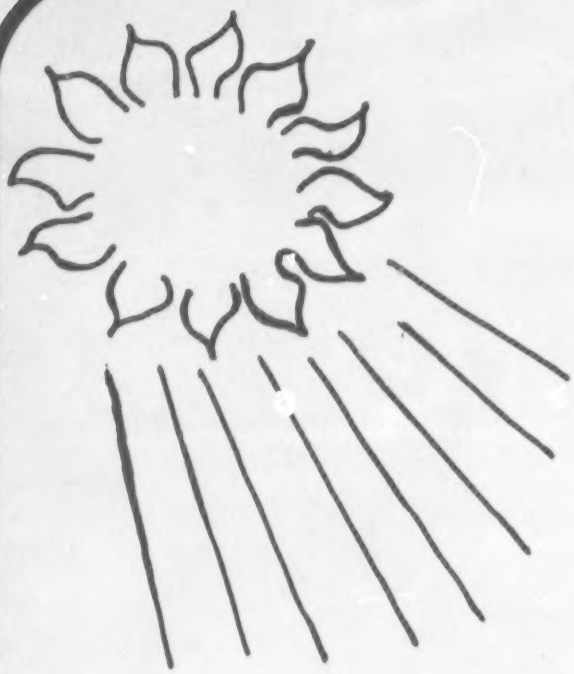




ENERGY PRODUCED AS A RESULT OF THE ELECTRIC FORCE

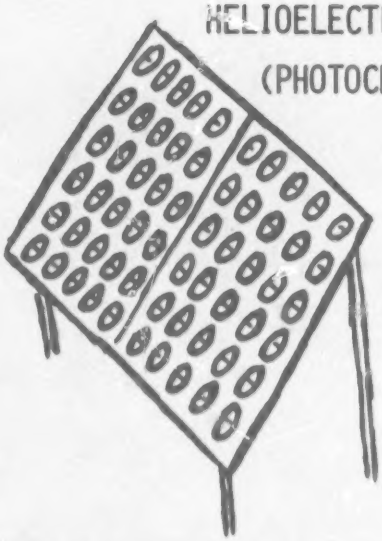
UNIT # 3 TOPIC LIGHT

VISUAL # 4

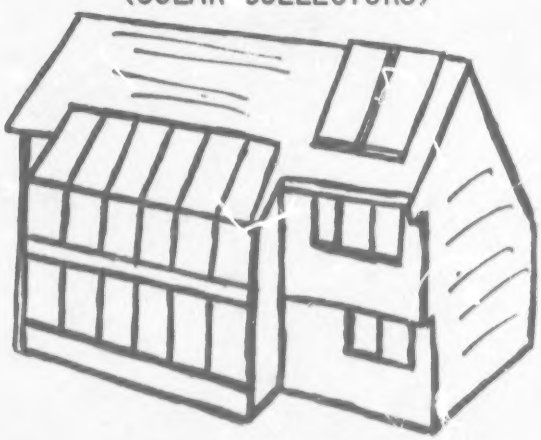


HELIOCHEMICAL
(PHOTOSYNTHESIS)

HELIOELECTRICAL
(PHOTOCELLS)



HELIOTHERMAL
(SOLAR COLLECTORS)



4. ELECTRICITY FROM THE SUN I
Solar Photovoltaic Energy

FACTSHEET

United States Department of Energy
Office of Education, Business & Labor Affairs

INTRODUCTION

As the electric bill rises steadily in spite of turned off lights and idle air conditioners, the sparkle of sunlight seems brighter and brighter. If only we could turn away from the fossilized secondary forms of solar energy and mainline it.

Solar radiation can be converted directly to electricity. This is accomplished routinely in the light meters built into popular camera equipment. The device which accomplishes this magic conversion, the solar cell, was developed in the 1950's at Bell Laboratories. The first strong commercial impetus came from the space program and much of the electronic equipment on the space vehicles is powered by similar devices. Solar cells are also used on communication and signaling equipment in isolated locations on this planet. To become a significant source of electrical energy for routine use, however, there must be several successful generations of research and development.

The best existing example of a large solar cell generator is the experimental 1000 watt (1 kw) array owned by the Mitre Corporation near Washington, D.C. It is constructed of 20 panels and each panel in turn contains 700 or so individual cells. It cost $30,000.

The present state of the art is summed up in the preceding three sentences. Solar cell arrays with large capacity for electric power production (1000 watts is about enough power for most household needs) can be constructed. They are, however, too expensive for practical use. Even with skyrocketing costs, conventional power plants can produce power at less than $1,000 per kilowatt.* The Mitre Corporation's array, at $30,000 per kilowatt, is the least expensive solar cell array (in terms of dollars per kilowatt) assembled up to 1975.

We will, in the sections which follow, describe how solar cells work, why they are expensive, and report on some of the budding ideas which may bring down their costs into the competitive range.

RESOURCES

The major attraction of solar energy is that it is free and plentiful. We have dwelt at some length in other "Fact Sheets" (see #7 "Solar Heating and Cooling", for instance) on the impressive size

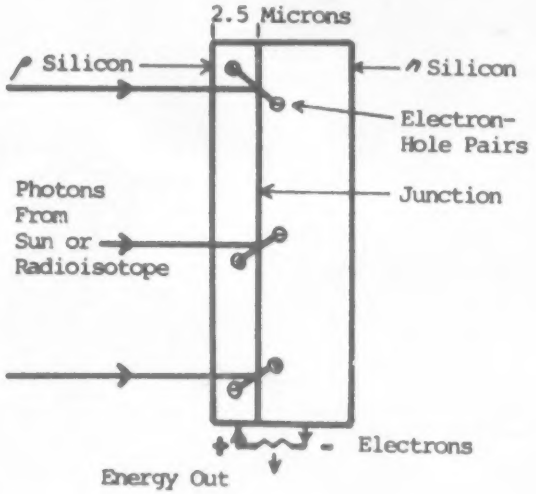
*Watts and kilowatts (1000 watts) are units of electric power. See the Glossary, Fact Sheet #18 for further definitions.

This material was produced by the National Science Teachers Association under contract No. EX-76-C-10-3841 with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

of the resource base. There is plenty of power available. The question is, how much can we get when it is needed-how do we run the lights at night? Even though solar cells do produce some energy from indirect light, storage will have to be provided for cloudy days. In Fact Sheet #7, there are maps showing the geographic and seasonal valuation of solar energy.

TECHNOLOGY

Although there are several ways by which radiant solar energy can be directly converted to electricity, the most promising method at the present is the "photovoltaic effect". "Photons," the "particles" which make up a beam of light, if they carry sufficient energy, can knock electrons loose from the atoms which they strike. The solar cell combines this property of light with the unusual properties of a "semiconductor"-the versatile devices which form the heart of transistors. A semiconductor consists of a junction between two dissimilar materials. A typical arrangement is shown below:



The p-region is transparent to light and very thin (about 3 x 10^{-4} cm or 0.001 inch). Photons of light entering this region, release electrons from the silicon atoms. The electrons flow in one direction across the junction and the holes move in the other direction. This sets up a potential difference, a voltage, and if circuitry is provided as shown, current will flow, electrons toward the positive terminal and holes in the opposite direction, and electric power will be available.

A high quality silicon solar cell is capable of producing a maximum current of about 30 milliamperes per cm^2 (0.030 amperes) and a maximum voltage of 500 millivolts (0.500 volts). The conditions for these maximum values are not, however, the same and the maximum power that can be generated in full sunlight is about 15 milliwatts/cm^2 (0.015 watts per square centimeter).

A typical solar cell is 2 cm by 2 cm, a surface area of 4 cm^2. Its power output is very small, about 0.60 watts and many cells must be connected together to obtain an appreciable power output. As an example, a 14 volt, one watt panel measures 150 x 150 x 30 millimeters (a surface area of 225 cm^2) and has a mass of one kilogram (about 2¼ pounds).

Silicon is the second most abundant material on the earth, it is the major constituent of common sand. It is thus not initially expensive, but to be efficient as a solar cell, it must be absolutely pure and, more importantly, it must be in a pure crystalline form. Such crystals are at present grown very slowly in small lots.

A cell is made by slicing a piece of single crystal into wafers 0.012 inches thick (wasting about half the crystal since the saw cut is about as thick as the wafer). Then very precise amounts of other materials are introduced into the two surfaces creating the n-type and p-type materials and the junction which is the boundary between them.

The requirement for extreme purity of the silicon and for a pure crystalline structure when combined with the need for great precision in the addition of doping materials, has so far required much careful hand work by highly skilled technicians and results in the high price. As an example, the basic 2 cm by 2 cm piece of silicon for a solar cell to be used in space costs about 40 cents, but the additional processing costs $4.00.

There are several approaches to reducing costs. Mass production systems are being designed to optimize each operation from the beginning, with sand as the raw material, to the finished cell. In a process being developed by Tyco Laboratories and Harvard University, a very thin die is lowered into molton silicon and silicon is drawn into it by capillary action (as water goes up in a thin tube). The silicon ribbon can then be pulled slowly through the die and holds that shape as it hardens. The ribbons can be cut and fashioned into solar cells without the costly grinding and polishing. Tyco hopes soon to be producing ribbons 50 to 100 feet long.

The other major direction for research and development is to improve the solar cell's efficiency. To generate 4000 Mw of electric power (about 1 percent of our present generating capacity) with 12 percent efficient solar cells would require 80 square miles of solar cell panels--about 100,000 tons of silicon.

Annual U.S. production of pure single-crystal silicon is about 500 tons at present.

The upper limit on cell efficiency is about 25 percent. Increased efficiency will lower the collecting area needed; doubling the efficiency cuts both the above figures in half. Other substances are being tried and one type, a gallium arsenic cell, with an efficiency of 18 percent was produced recently. Cadmium-sulfide cells also have their backers.

It is not impossible that new photovoltaic substances will be used. A cell made of a junction between glass and inexpensive polycrystalline silicon (a conglomerate of crystals rather than a single crystal) has demonstrated an efficiency of 7 percent and may provide an inexpensive solution. There is also experimentation underway with combinations of solar cells and sunlight concentrators--mirrors or lenses--which increase the output by focusing more sunlight on the cells.

PRESENT AND PROPOSED SYSTEMS

A solar cell industry is already in existence in this country, producing 1000 to 1500 m^2 of solar cells with a generation capacity of perhaps 100,000 watts annually for a market of more than $5 million per year. The space industry has been the major customer, but not the only one. Solar cells are used also at remote locations on earth and aboard private and commercial boats to charge batteries and power communication systems, etc.

Larger scale generation of electricity is in a much more primitive stage of development. The 1 kw solar array of the Mitre Corporation is being tested as a prototype household energy source. An auxiliary storage system is also under development and they will experiment with hydrogen production by electrolysis. The hydrogen can be used with a fuel cell to produce electricity on cloudy days.

A second approach is taken by the Institute of Energy Conservation at the University of Delaware. The center attraction for this study is Solar One, an experimental solar-powered house. The heart of the system under study at Solar One is a rooftop unit combining a solar thermal collector for heating and cooling with solar photovoltaic devices for electricity. The project director, physicist Karl Böer, estimates that almost 90 percent of the household energy requirements could be met.

With such a combination, overall efficiencies as high as 60 percent are expected. A novel feature is the two-way connection with the conventional electric utility system. During peak sunlight, the cells would produce more electricity than needed. This surplus would be fed into the utility network for use elsewhere. Since the utility load usually peaks in the daylight and in the summer, times when solar output is a maximum, this assistance would be appreciated and perhaps credited. Böer anticipates that solar generation of this type might reduce peak loads by 10 to 20 percent without the need for major electrical storage.

Solar Ope will be an important proving ground. There are many difficulties to be worked out, ranging from the technical and economic relations with the utility, to the problems of dirt and bird droppings on the collectors. It is thus much too early to speak of costs, but one estimate sets the costs of a 3 ft by 4 ft solar panel at 93¢/ft^2, plastic and glass coverings at 83¢/ft^2, and insulation at 10¢/ft^2, for a total of $1.86/$ft^2$. To this Böer adds $3.50/$ft^2$ installation costs and projects electricty costs of 2 or 3 cents per kw-hr.

Hardly an example of existing practice and a literal "blue sky" proposal is the one put forward by Peter Glaser of Arthur D. Little, Inc. for a Satellite Solar Power Station. This ambitious plan calls for a satellite with two wing-like solar panels, each about 3 miles on a side. The satellite would be put into a synchronous orbit; fixed above a spot on the Earth (22,000 or so miles above the Earth's surface) and since it would always be in the sunlight, would receive about seven times as much solar energy as an Earth-based panel. Th electric energy would be converted to microwav radiation and beamed to Earth where it would b collected and reconverted. It is calculated that the solar satellite would produce more energy in two years than was used to build it and put it in space.

A satellite of this size is about 10,000 times larger than any satellite which we have so far orbited and a host of others problems have to be solved. It is clearly a vision for the next century.

ENVIRONMENTAL EFFECTS

Solar cells have a generally benign direct environmental impact. The largest problem is the amount of land needed. If a target generation of 1 x 10 kw-hr/year is chosen (a reasonable target for early in the next century), then about 0.1 percent of the U.S. land will have to be dedicated to this purpose. This huge amount of land--20 million acres--covered with 10 percent efficient solar cells would produce about 6 percent of all electric energy we expect to use in 2020. It is a lot of land, but highways now cover 5 times as much land and crop land is 100 times larger.

Houses themselves--single family residences--cover half as much land as is required and much of the generation may be roof top. This not only saves land, but offers the possibility of reducing the need for transmission lines, an economic and aesthetic benefit.

There will be significant indirect environmental impact. The energy to process the millions of solar cells will inevitably add to the environmental burden. It may take years, as it did in the nuclear industry, for energy production by solar cells to catch up with the energy expended in their construction.

SUMMARY

Photovoltaic conversion of sunlight to electrical energy is presently accomplished, but at a high price. The manufacturers estimate costs of less than $15,000 for large orders, but this is still 15 to 20 times higher than the present most expensive nuclear or fossil fuel generation costs.

Mass production techniques from sand to cells, new methods of growing silicon ribbons, use of new materials, including polycrystalline materials and glass, and types of cells which use other effects than the p-n junction should eventually lower prices. In addition to the research, there are equally difficult problems of installation, storage, utility interconnection, etc., to be solved.

Solar power has become a popular issue, but some proponents expect too much too soon and the figures we have quoted should temper unbridled optimism. Many feel, however, that Federal optimism has been too bridled. The goals of the most recent National Solar Energy Research Development and Demonstration Program (ERDA-49) are for 100 Mv of photovoltaic generating capacity by 1985 and 30,000 Mv by the year 2000. In support of this, the funding is expected to grow from $5 million by 1980. It appears, however, that the popularity of solar energy in Congress is so great that more funds than requested will not only be authorized, but appropriated. The American people are turned on to the idea of free energy from the sun (at almost any cost, apparently), and the solar era may dawn more brightly and quickly than expected.

REFERENCES

1. Solar Energy for Earth, American Institute or Aeronautics and Astronautics, April 21, 1975, see esp. Chapter VII, "Photovoltaic Power," pp. 46-59.

2. "Solar Cells: When Will You Plug Into Electricity from Sunshine?" Jon F. Free, Popular Science, 205, 52-55, 230-121, December 1974.

3. "Energy Crisis Spurs Development of Photovoltaic Power Sources," A. Rosenblatt, Electronics, 47, 99-111, April 4, 1974.

4. "The Photovoltaic Generation of Electricity," Bruce Chalmers, Scientific American, 235 (4): 34-44, October 1976.

5. "Photovoltaic Solar Energy Conversion," M. Wolf, Bulletin of the Atomic Scientists, 32, 26-33, April 1976.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

5. ELECTRICITY FROM THE SUN II
Solar Thermal Energy Conversion

Printed 1977
Reprinted June 1978

FACTSHEET

United States Department of Energy
Assistant Secretary for Intergovernmental and Institutional Relations
Education Programs Division

INTRODUCTION

The radiant energy of sunlight is converted to many different forms of energy after it strikes the Earth. It becomes chemical potential energy through the process of photosynthesis; it can evaporate water and thus be stored as latent heat; or it can be directly absorbed by matter as heat energy. The conversion to heat energy is a most efficient one; a blackened surface can absorb 85 to 90 percent of the energy striking it. Photosynthesis, on the other hand, is less than 1 percent efficient, and the direct conversion of solar energy to electrical energy through currently produced solar cells (see Fact Sheet #4) is less than 25 percent efficient.

The high efficiency of thermal conversion of radiant energy makes it an attractive technology. Much of our energy - more than half - is consumed as heat. If the thermal energy is used to produce steam, then steam turbines can be burned and generators can produce electricity - also a popular form of energy.

The practical application of solar thermal conversion (STC) has appealed to visionary engineers for centuries. Archimedes is credited with an imaginative military application in 212 B.C., using sunlight to set the sails of an invading fleet afire.

Solar energy was used for water distillation in the 1880's near Salinas, Chile and provided 5,000 gallons of fresh water per day by distilling sea water. A prototype solar engine was built on the Nile River, near Cairo, Egypt in 1909 to provide irrigation water.

The rising cost of all forms of energy, the growing dependence on foreign oil, and the energy-related abuses of the environment have all conspired to cause us to turn to solar energy with money and scientific manpower. A large scale attempt to harness this source is underway. In addition to solar sea plants, bioconversion techniques, and photovoltaic devices, there is now solid support for the development of thermal conversion technologies. The Energy Research and Development Administration (ERDA) has committed $38 million in Fiscal Year 1976 and annual expenditures in this area are expected to grow in Fiscal Year 1977 and to reach a level of more than $80 million the following year. By the year 2000, some 20,000 Mw* of solar thermal generating capacity has been estimated.

RESOURCES

We have discussed the resource base for solar energy in other Fact Sheets. The solar energy input is so large that it will not be a constraint in the forseeable future. The input of solar power on the U.S. land area is almost 1000 times the power output. The energy is free; the deterrent to immediate reliance on the sun is in the cost of the plants and the land needed for energy collection.

*Mw, megawatt, a million watts. Further definition of this unit of electrical power can be found in the Glossary, Fact Sheet #18.

This material was produced by the National Science Teachers Association under Contract No. EX-76-C-10-3841 with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

LECTURE NOTES

TECHNOLOGY

Solar Thermal Conversion technologies can be grouped into three categories: central receiver plants, distributed systems, and total energy systems. The first two of these are thermal to electric conversions; in the total energy concept the plant would not only provide electrical energy but would also use thermal energy directly for heating and cooling.

The total energy system will first prove practical, it appears, for new installations - military bases, new residental installations (new towns or rural communities), or large industrial groupings. The technology needed for new systems will be a mixture of thermal - mechanical - electrical conversion technology and the solar heating and cooling technology such as is discussed in Fact Sheet #7. We will not consider this third category further in this Fact Sheet. The fairly conservative projection of its importance is for 8,000 Mw of thermal energy to be produced by such systems by the year 2000.

The other two types, central receiver plants and distributed systems, have several common features but differ significantly in the basic technology. Both need large collection areas to gather in the abundant, but diffuse daily offering of solar energy. Both must have means to store energy and both require a heat engine to convert the heat energy to mechanical work.

In the central receiver design, however, solar energy is harvested by focusing collectors and is transmitted optically (as light) to a central receiver. In the distributed system the energy is converted into thermal energy by the collectors themselves and is transmitted to the power plant by a heat exchange medium, air, water, oil, or a liquid metal.

The central receiver system has apparently been selected for early emphasis. In concept it will consist of a receiver - a boiler mounted on a tower - and a collecting field of mirrors which focus the radiant energy on the tower. These mirrors can either be parabolic devices which track the sun separately and focus light on the boiler, or they can be flat mirrors arranged all around the tower in a group so that together they approximate one big parabolic mirror. They can track the sun in both the east-west and north-south movements or in only one of these. They can track individually or be mounted in small groups on a platform which itself does the tracking.

The problems and expense lie in providing for the power and control of tracking and in the cost of the mirror materials. The mirrors must be lightweight to reduce cost and simplify the tracking. Plastic with metallic coatings seem to be preferred material, but the mirrors must not flap in the breeze. Covering each with a protective plastic bubble is being investigated.

Two different types of receivers are being considered: "cavity absorbers" and "open-face absorbers". In the former a sharply focused beam of light enters through a hole and is essentially trapped inside the boiler giving up energy to the coils containing heat exchange fluid (usually water). In the "open-face" design the whole boiler surface absorbs and so a sharply focused beam is not needed. This reduces the precision needed in collectors and tracking systems.

The two major advantages of the central receiver system lie in the efficiency of the energy transfer process and in the resulting high temperatures. The energy is transferred as light and so the only losses are reflection losses at the collector and at the receiver. Efficiencies of 80 or 90 percent seem practical.

The focusing of a whole field of mirrors on the one receiver produces a considerable concentration of energy; as much as 1000 is considered possible. (This means that the energy falling on a square meter of receiver surface can be 1000 times as great as the energy per m^2 of normal sunlight.) The large concentration results in the production of very high temperatures. The great solar furnace in the French Pyrennes (used for high temperature research) can, on a clear day, produce temperatures as high as 6,000° F. It is anticipated that the central receiver systems being designed will produce supersaturated steam at 900 to 1000° F, temperatures comparable with those in modern coal-fired plants and hotter than the steam in most current nuclear plants.

The high temperature operation allows for efficient conversion - 40 percent conversion efficiency in the steam turbines should be fairly easily obtained - and it also allows current steam generation technology to be used.

The major advantage of the distributed collector system is that it can produce some energy from indirect light (light under hazy conditions) while the central receiver, with its optical focusing, works only in full sunlight. This advantage is considerabley reduced, how-

ever, by the lower operating temperature and the subsequent reduction in efficiency.

In the distributed system the heat exchange takes place at the collector itself rather than in the boiler as with the central receiver system. The radiant energy from the sun is converted to heat energy in the absorbing surface and this heat energy is transferred to water or some other working fluid (it may be oil or a liquid metal) and pumped back to the central plant where the energy is ultimately collected and stored.

The resulting temperatures are lower than those attained in the central receiver. They range from 200° F to 500° F and are thus less efficient for power production. At such temperatures it is likely that other working fluids than steam, for example the refrigerator gas freon, will be used. The development of large scale heat exchange and turbine generators for such materials will be one of the opening tasks for the developers of the distributed system STC. The flat plate collectors are well advanced in their design and testing, due to their applicability in home heating and cooling, and it is hoped that mass production efficiency will lower their cost so much that they can compete in spite of their inefficiencies.

A somewhat more sophisticated distributed system would use parabolic trough concentrators. These devices consist of long reflecting troughs with a parabolic cross section which focuses the sunlight on a pipe carrying the heat collecting fluid through the trough. In an advanced design worked out by Winston of Argonne National Laboratory, some focusing is achieved even for indirect sunlight and a concentration factor of 10 is expected. Although some of the parabolic troughs will need to be continuously pointed at the sun to achieve reasonable concentration, the Winston trough does not need the added expense of tracking.

The Winston collector is expected to produce temperatures up to 500° F, making it useful for heating and cooling or for total energy systems. The tracking parabolic concentrators can produce concentration ratios of 30 to 50 and temperatures in the 600° to 800° F range.

A problem, shared by both central receiver and distributed systems, is that of storing heat energy. The sun doesn't always shine. A large supplementary tank of the working fluid can provide enough storage to smooth out small fluctuations. If some fluid other than water is used, overnight storage can be accomplished in the same way, with a larger tank. Steam cannot be stored successfully and so steam plants require a separate storage system, with crushed rock for instance, and considerable energy is lost in the exchange. The technology of heat storage is not well developed and continued research may produce new solutions.

It may also, of course, prove attractive to store energy in electrical form (in batteries), or as gravitational potential energy in pumped water or compressed air, or as chemical energy in hydrogen. We will discuss such storage techniques in Fact Sheet #16.

ECONOMICS

Energy from the sun is free, but currently available collecting systems are more expensive to use than conventional energy systems. However, the anticipated escalation in cost of other energy forms and the cost reduction in mass produced solar energy systems make future competitiveness of solar-produced electricity a realistic vision.

Solar electric installations are capital-intensive. The central receiver plant, the most efficient of the alternatives, requires 1 km^2 per 100 Mw (1 km^2 = 0.39 mi^2 or 250 acres). With the cost of construction, interest, land, storage capacity, etc. taken into account, the cost of the electricity, in 1974 dollars, from such a plant is estimated at about 23 mills (0.023 cents) per kw-hr. Such a cost is competitive, it appears, with other forms of electric power generation. The spread of costs for nuclear and fossil plants with the same assumptions is from 12 to 17 mills per kw-hr.

Although the price per kw-hr may be competitive, the economic feasibility of STC systems will depend crucially on how they are used. They do not lend themselves to base load operation since the expected load factor (the percentage of the time they produce at their rated capacity) is only about 25 percent. They will, at least in their first realization, be used as intermediate load plants and be expected to provide part of the daytime peak load. It will take substantial breakthroughs in storage technology to allow STC plants to take on full time production responsibilities.

ENVIRONMENTAL PROBLEMS

In addition to their use of a renewable form

of energy, the other major advantage of STC plants should be their mild (or zero) impact on the environment. They emit no pollutants and present no danger of accident and thus could be constructed near population centers. There are questions to be answered concerning the impact of large areas of collectors in the desert and a possibility of local climate alterations caused by a hot central receiver boiler - it might cause strong local winds due to thermal lift at the tower.

The one major problem that STC plants share with conventional plants is the problem of waste heat disposal. As long as steam generation is the major conversion technique, there will be heat energy to dispose of. Unlike the conventional plants, however, the STC plants do not change the net balance. The solar energy is merely redistributed, collected over a wide area, and released at the generation site. Location of these plants in the water-short Southwest will probably require closed wet or dry cooling systems.

SUMMARY

The escalation in cost of other forms of energy has pushed solar thermal conversion to the brink of competitiveness with other forms of electrical generation. The three systems being considered are: the central receiver system (in which mirrors focus solar radiation on a large boiler); the distributed system (in which the radiant energy is converted at each collector and transported to the generating plant by a suitable heat exchange material); and the total energy system (in which solar energy is used both for heating and cooling and for the generation of electricity). The total energy system would be used with a residential complex, military installation, etc.

The initial emphasis for development will be on the central receiver system. A 5 Mw thermal test facility (a facility which will produce 5 Mw of heat energy not 5 Mw of electrical energy) is being designed for installation in New Mexico and construction has begun this year. It is expected that a 10 Mwe (electric) pilot plant will be completed by 1981 and that a 100 Mwe demonstration plant will follow if the pilot tests are encouraging.

Sites for solar total energy systems are being investigated and detailed design of a pilot plant should begin this year. A facility for testing the components of the distributed collector concept is currently operational in New Mexico.

Economic projections are that STC plants may be able to produce electric energy at prices ranging from 3-5 cents per kw-hr (1974 dollars) which should make them competitive with fossil plants for intermediate and peaking applications - that is to provide additional electricity during heavy use, daytime hours. Cost estimates of the energy produced by total energy systems fall in the range of $2 to $4 per million Btu (oil at $12 per barrel costs $2 per million Btu).

Tentative projections for the impact of STC plants are presently set at 40,000 Mw of electrical generating capacity and 8,000 Mw of total energy plant capacity by the year 2000. The long range hope is that STC might provide more than 10 percent of this country's electrical power. It is a hope which will receive crucial testing in this decade.

REFERENCES

1. Solar Energy, Energy Research and Development Administration, ERDA-Technical Information Center, P.O. Box 62, Oak Ridge, Tenn. 37830 (see Chap. III).

2. "Physics Looks at Solar Energy", Aden Baker Meinel and Marjorie Pettit Meinel, Physics Today: 44-50, February, 1972.

3. "Solar Thermal Electric Power", Robert L. Gervais and Piet B. Box, Astronautics and Aeronautics: 38-45, November, 1975.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

7. SOLAR HEATING AND COOLING

John M. Fowler

FACTSHEET

United States Department of Energy
Assistant Secretary for Intergovernmental and Institutional Relations
Education Programs Division

INTRODUCTION

Human kind has always looked to the sun for warmth. It was our only source of heat during those hundreds of thousands of years of fireless prehistory and, since fires themselves are so inefficient, was still the major source of heat until the real beginnings of the industrial age 200 to 300 years ago.

Primitive solar heating was relatively technology-free. Our ancestors took the sun's heat when and where they could get it. In the past few generations, however, our expectations of comfort have changed and we have become accustomed to a dwelling that is warm throughout, not just around the fireplace. In the warmer, affluent countries we also expect summertime air-conditioning of our houses, offices, cars, and even apparently, our ball parks. We not only want all of the building heated or cooled, but also want immediate control over the temperature and now must rely on electrical or fuel burning furnaces, air conditioners, and hot water heaters.

Solar heating and cooling technology, however, has existed for some time. The MIT solar house in Boston has obtained more than half of its heat energy from the sun for 20 years. There were perhaps 50,000 solar hot water heaters in Florida in the 30's and 40's and evaporative coolers for home air-conditioning are still used in the Southwest. Although there are no published estimates for the percentage of clothes dried by solar energy we would guess that backyard clothesline loads are still far heavier than those processed by electric and gas-heated indoor dryers.

For all its impressive history, however, solar space and water heating, and solar cooling do not replace at present more than an infinitesimal amount of fossil fuel-derived energy in this country and do only a little better in such sunnier climates as Israel and Japan.

The return to this source has begun. The rapidly climbing price of fuel and electricity and the vision of replacing foreign oil imports has stimulated governmental support of solar research and development. The 1980's and 90's and beyond may be solar years.

RESOURCES

A major advantage of solar energy is the amount of resource. The rate at which solar energy falls on the upper atmosphere (the power input) is 1.36 kw/m^2 (kilowatts per square meter) or 130 watts per square foot.* About a third of this energy is immediately reflected away. The amount which arrives at the ground depends critically on latitude, the season, local weather conditions, etc., but the day/night U.S. average is 177 watts/m^2--13 percent of the original power. This is not a lot of power--it would take almost a meter square collector to provide enough power for a 200 watt bulb. It adds up, however; in 24

*A watt is a unit of electrical power and a kilowatt (kw) is 1,000 watts. For definition and discussion of these and other units see the Glossary, Fact Sheet #18.

This material was produced by the National Science Teachers Association under contract with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

hours this is a little more than 4 kw-hr/m^2 or 3770 Calories/m^2. The energy equivalent of 10 barrels of oil falls on each U.S. acre per day and the equivalent of 22.4 billion barrels of oil per day on the 2,310 million acres of the 48 contiguous U.S. states (almost 4 times our present yearly oil consumption).

The resource base is thus more than adequate. The amount of solar energy available at any given time, however, varies greatly. Some idea of the geographical and seasonal variation is given by the two illustrations below.

JANUARY

JULY

Lines of equal total daily solar energy at the ground on cloudless days (solid lines) and on days of average cloudiness (dotted lines) in January and July. Units are Calories (kilocalories) per square meter per day. The annual average for the United States is 3770 Calories per m^2 per day, 58 Btu per square foot per hour.

We see, for instance, from the first of these that the daily flux of solar energy in a band across the Midwest in January is about 2500 Calories per square meter (it lies between the 3000 and 2000 Calorie lines). In July the central U.S. gets about 7500 Calories per square meter. (These data can be converted to Btu per square foot per hour by dividing each of the Calorie/m^2 numbers by 65.)

Using the January data, a typical three bedroom house in Connecticut, with 1,000 ft^2 (90m^2) of roof area would receive 5.6 million Calories in that month. Even at 50 percent efficiency, a roof full of collectors could provide more than half of the 4.8 million Calories such a house would typically require in the winter. We have deliberately chosen a pessimistic case, a Northern state and a winter month, to make the point that solar energy can provide important amounts of heat even in the North.

TECHNOLOGY

We will discuss in this section three solar possibilities: solar space and water heating--which are essentially similar--and solar cooling. Styles of solar space heating can be categorized as either active or passive. In an active solar house, energy is collected by a system of solar collectors, typically on the roof. The heat energy is carried away by water or air and transferred into some large storage system. From the storage unit, it is then circulated, as required, throughout the house by either a hot water or hot air system of conventional design.

In a passive system there is no circulation to storage. Passive solar houses are most useful in generally sunny regions. They tend to be custom designed, energy efficient in all ways and do not lend themselves to general description.

The active houses are of more commercial interest since the solar heating component is a complete system, often one that can be installed--"retrofitted"--in an existing house. The major components are described below.

Collector: The "flat plate" collector is the most common; a box one meter on a side, 15 to 20 cm thick covered by a transparent plate of glass or plastic. The back is blackened to absorb solar radiation and the heat that is generated in this absorber is carried away by water (in pipes or trickling across the surface) or by the air. In sophisticated systems the interior is a partial vacuum to reduce energy losses, the windows are double-layered or specially coated to admit incoming radiation but trap outgoing heat radiation. Special coatings increase the absorptive power of the back plate.

Storage: A second component of a solar heating system is the heat storage unit which is needed to provide for nights and cloudy days. The common storage medium is water in an insulated tank. When the heating system circulates air, however, crushed rocks or pebbles are often used. Since water has a

higher heat capacity than stone (it can store heat per pound) the storage volume of water is less.

The usual "rule of thumb" for 2 or 3 days of storage is 1.5 gallons of water storage per square foot of collector. If rocks are used the space provided must be larger. The rule of thumb is 60 lbs of rock per ft^2 of collector.

There are promising experiments underway with more sophisticated storage techniques using solid materials (eutectic salts) which melt at about 100° F and then give up stored heat when they cool and solidify. Commercial realization of this type of storage is still somewhere in the future.

Solar Cooling: At first thought it seems incongruous to consider cooling with solar energy. Evaporate coolers, however, are still popular in the Southwest. Water is evaporated as it runs down over a system of pipes and the water in the pipes, cooled by the evaporation, is then circulated through the house.

A better system is the "absorption-desorption" principle that was used in the old Servel refrigerator which obtained its energy from a gas flame. A refrigerator is a "heat pump". Heat is transferred by exposing an expanded and, therefore cold, gas to the cool interior, compressing it so that its temperature increases and allowing it to discharge this heat outside. In the electrical refrigerator, pumps and compressors are used. In a heat-activated refrigerator, the heat drives a vapor out of a liquid which expands, cools, picks up heat, and is then re-absorbed in the liquid to carry the heat away. The major difficulty with solar cooling units of this type is that temperatures of 200° F or higher are needed. Since flat plate collectors cannot easily produce temperatures higher than 150° F, some kind of concentrator will be needed.

Solar cooling promises to make a most important energy contribution. Its major competition is expensive electricity, for which the demand usually peaks in the summer—when there is plenty of sun.

Heat Pumps: There is growing interest in combinations of heat pumps and solar systems. A heat pump moves energy from one place to another. It is reversible and thus can pump heat from a storage tank (or the outside air) into a building in the winter and from the indoors out in the summer. An attractive combination is to use solar collectors to warm water in the winter and to draw from this with a heat pump. The heat pump works best when the temperature difference between its source and the interior is not too great; the solar collectors work best when they do not have to provide really hot water. The efficiency of both systems is thus improved.

ECONOMICS

The existing examples of solar houses are so unique as to make general economic operations difficult. Solar installations are expensive and the savings must accumulate over time and be balanced against interest on the money on the one hand and rising costs of conventional fuels on the other. It also seems clear that at most locations it will not pay to build enough collector area to provide all the needed heat; 60 to 70 percent will probably be the optimum.

It appears from studies to date that solar heating is already competitive with all-electric heating and is approaching a competitive posture with other fuels. If hot water heating is also taken into account, the balance swings more toward solar and when solar cooling devices are projected the competition should favor solar in most parts of the country. It will be possible to give a much more precise description and analysis of solar heating and cooling in three or four years. For all its cost, installation of solar equipment is booming. Government buildings, schools, multifamily units are now being designed and built using this energy source. Economical or not, we are turning again to the sun and it is, in fact, reasonable to expect this increasing demand itself to stimulate the competition which will produce more economical systems.

SUMMARY

The combination of a large resource base, free fuel, and a market (for space heating and cooling) consisting of 25 percent of the total U.S. energy consumption has made solar energy a favorite panacea for our energy crisis. While most careful economic analyses, which compare the system costs and the cost of the capital investment with the present cost of other fuel, show solar heating to be, at best, marginally economic, the boom seems to be under way.

Economic performance is not yet established. Systems and assumptions differ widely. A recent ERDA economic analysis gives the following guidelines:

"...for fuel costs in the $10-per-million Btu range (equivalant to about 3 cents per kilowatt-hour which is near the average electricity cost in the U.S.), solar heating system costs must be below $15 per square foot

of installed collector.

They point out that recently completed buildings are beginning to show costs in this range although experimental, high performance systems still cost from $20 to $50 per square foot.

Solar energy has attractions which are not measured by these economic studies. It is environmentally satisfying to the energy conscious and it assures some heat to the user, a not unimportant consideration in the present climate of embargo and unanticipated crises.

The growth of solar heating and cooling is being stimulated by tax benefits in states like Arizona and Maryland, and in Florida, by the requirement that all new housing contain plumbing for solar water heating.

At the Federal level there is also much support. The Heating and Cooling Act of 1974 (which received an initial $60 million authorization) had a minimal goal of 350 residential and 50 commercial demonstration units. The ERDA budget for FY77 is $86 million. It is estimated that private investment at least equals federal support, and this investment is being made not only by the newly formed small companies, but also by such giants as Pittsburg Plate Glass, Revere Copper and Brass, Exxon, Corning Glass, and Bowing. Some 700,000 square feet of solar collectors were produced in 1975 and the total cost of installed units in that year was about $10 million. An industry of $1 billion by 1980 has been forecast.

The actual contribution of solar heating and cooling to the total energy use is, of course, insignificant to date, but there is also optimism here. The ERDA projection is for 3×10^{15} Btu by 2000. By 2020, an impressive 20×10^{15} out of a total of 180×10^{15} Btu is projected. As optimistic as these figures may seem in the light of the few hundred buildings which comprise our present experience, they may, in fact, turn out to be under-estimates. The public is entranced by this form of energy and may demand it faster than economic considerations warrant. We are getting turned on by the sun.

REFERENCES

1. "Solar Heating and Cooling", J.A. Duffre and W.A. Beckman, Science, 191:143-149, January 16, 1976.
2. Buying Solar, Federal Energy Administration, (Washington:USGPO), June 1976 (Stock No. 906-C59).
3. "Solar Heating and Cooling", J. Grey, Astronautics and Aeronautics, 33-37, November 1975.
4. "Active-Type Solar Heating Systems for Houses: A Technology in Ferment", W.A. Shurcliff, Bulletin of the Atomic Scientists, 32: 30-40, February 1976.
5. "Low Technology Solar Homes That Work With Nature", Travis and Price, Popular Science, 209:95-98, December 1976.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources Environmental Impacts
18. Alternative Energy Sources A Glossary of Terms
19. Alternative Energy Sources A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

Printed 1977
Reprinted September 1978

CURRICULUM GUIDE OUTLINE:

- 3.40 MECHANICAL
  - 3.41 WIND
    - 3.411 CLIMATE AND ATMOSPHERIC CONDITIONS
    - 3.412 WIND-DRIVEN GENERATORS AND ALTERNATORS
    - 3.413 BLADES AND HUBS
  - 3.42 WATER
    - 3.421 TIDAL
    - 3.422 WAVES
    - 3.423 MEASURING AVAILABLE WATER POWER
    - 3.424 DAMS
    - 3.425 CHANNEL, SLUICES AND PIPES
  - 3.43 GRAVITATIONAL

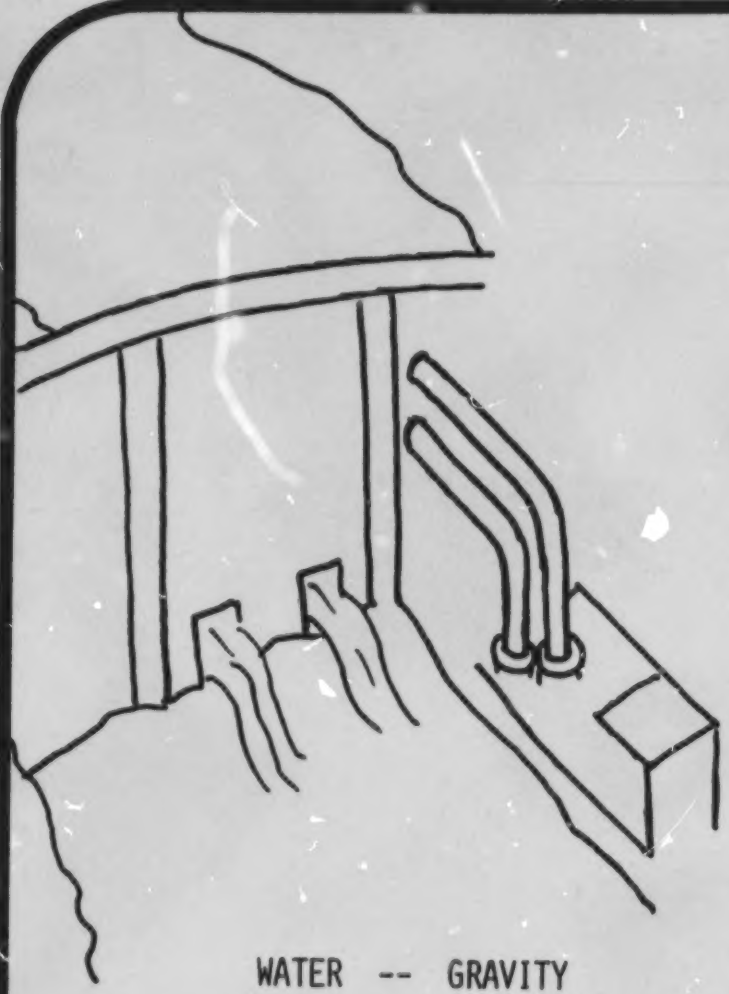
MECHANICAL ENERGY IS AVAILABLE IN BOTH KINETIC AND POTENTIAL FORMS. WIND, WAVES AND TIDES POSSESS ENERGY IN MOTION, WHILE POTENTIAL ENERGY IS STORED BEHIND DAMS. REFER TO VISUAL #5 AND FACT SHEET #3 FOR A DISCUSSION OF WIND ENERGY. POPULAR SCIENCE MAGAZINE NOVEMBER 1977, AUGUST 1978, CONTAIN INFORMATION ON WAVE ENERGY.

CURRICULUM GUIDE OUTLINE:

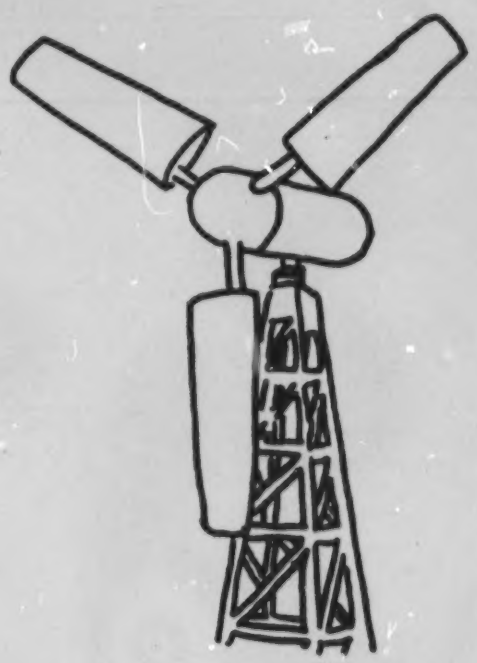
- 3.50 NUCLEAR
  - 3.51 ATOMIC, RADIOACTIVE
    - 3.511 ATOMIC THEORY
    - 3.512 CHEMICAL ENERGY
    - 3.513 ELECTRONS AND ENERGY
    - 3.514 NUCLEAR FUELS
    - 3.515 REACTOR PRINCIPLES AND POWER
  - 3.52 SOLAR
    - 3.521 ENERGY OF THE SUN
    - 3.522 ENERGY OF RADIOACTIVITY
    - 3.523 NUCLEAR FISSION
    - 3.524 NUCLEAR FUSION

5

VISUAL #



WATER -- GRAVITY



WIND

WAVES - TIDES ARTICULATED PONTOONS

FACTSHEET

Office of Education, Business & Labor Affairs

United States Department of Energy

3. WIND POWER

INTRODUCTION

For centuries, power from the wind has been used to pump water for crop irrigation, to propel sailing ships across the oceans, and to turn millstones to grind flour from grain. From its origins in Persia in the 7th century, the windmill concept spread throughout the Islamic world and reached Iran and China by the time of the Mongol conquests. In the 11th century, windmills appeared on the farms of western Europe and, by the 17th century, the Netherlands had become the world's most industrialized nation by extensive use of wind power to drive trading ships, to power grinding mills, and to pump water from lands that were once beneath the sea.

Over the centuries, the original windmill design was refined and improved. By 1850, use of windmills in America to pump water and turn sawmills represented 1.4 billion horsepower-hours-of-work, an amount equivalent to 11.83 million tons of coal.

This growth was curtailed somewhat by the introduction of the steam engine, but interest picked up again as settlers moved out into the American West and Great Plains areas. By 1900, a large windmill industry existed in the United States with a capital investment of over $4 million. By the 1920's, wind power had become a major source of electrical power on farms and homesteads across the United States. Similar developments took place in Europe. These small-scale generators served well for years, providing cheap, clean electrical power to thousands of rural and farm homes. However, the establishment of the Rural Electrical Administration (REA) in 1930 made federally-subsidized, centrally-generated electrical power available to farms. Installation of all the cables took about twenty years, but by 1950, small-scale windmills were a thing of the past.

Interest remained in the potential of large-scale wind generators, however, and between 1935 and 1955 a number of machines, ranging in power from 90 kw to 1.25 Mw* were built. One of the largest and most well-known, the 1.25 Mw Smith-Putnam generator, was built on "Grandpa's Knob" in the mountains of central Vermont. While the success of that experiment was short-lived, due to mechanical failure and the complications and expense of war-time materials supply, it did demonstrate the feasibility of capturing wind power for electrical generation on a large scale.

Wind power differs from most other "alternative energy technologies" in that it is an old and proven source. Its demise was brought about to some degree by the overly optimistic projections of cheap nuclear power and the unrealistic energy prices of the 50's and early 60's. It is a technology which could by quickly brought to large scale use given determination and support on the part of the private and public sectors.

* See Glossary for definition (Fact Sheet #18).

This material was produced by the National Science Teachers Association under Contract No. EX-76-C-10-3841 with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

LECTURE NOTES

RESOURCES

About 2 percent of all the solar radiation that falls on the Earth is converted to wind energy in the atmoshpere. Calculations have shown that the amount of wind available over the continental United States is about 14 times the 1973 energy demand of the U.S. A 1973 NSF/NASA solar panel study estimates that an annual output of 5.1×10^{15} Btu's of wind energy would be possible by the year 2000. That amount is close to the total electrical demand in the U.S. for the year 1970 and would represent about 5 to 10 percent of our total energy needs in the year 2000.

TECHNOLOGY

The basic configuration of windmills, which has remained unchanged for centuries, is a horizontal shaft to which is attached a number of blades designed to turn in the wind. This provides mechanical energy to turn a mill, or pump water, or turn a generator which will produce electricity. The ideal wind machine has not yet been invented, but the laws of physics tell us that it should be able to capture about 59 percent of the kinetic energy of the wind that passes through the sweep of its blades. Actually, blade inefficiencies and mechanical losses reduce practical efficiencies to about 35 percent.

The power output of a wind machine depends both on wind velocity (or speed) and on the diameter of the blades. For maximum power, then, a wind machine should have the longest blades possible (about 100 feet is the maximum now) and should be located in the strongest winds. The height of the wind machine is another important factor because there is greater wind speed and constancy at higher altitudes than at the Earth's surface. The expense of building a tower also increases with its height, however, so that most present designs call for a tower between 100 and 150 feet high.

The major deterrent to wind power is the relatively high cost per unit of power output from the wind generating machines due to the variable nature of wind energy. On the average, "energy winds," those with speeds of 10-25 mph, blow only about two days out of the week in the United States. The more common winds, called "prevalent winds," blow the other five days and have a speed of 5-15 mph. Wind power generators operate at their rated capacity only when the wind is blowing at or above some minimum speed. Thus, a typical wind power generator operates at an overall load factor between 15 and 25 percent--which means it can only produce one-fourth or so of the total energy produced by a conventional plant of the same generating capacity.

Wind variability also has an effect on rotor revolutions per minute, which in turn influences the output frequency of the generator. Since standard U.S. power networks require constant frequency (60 cycles per second) and Alternating Current (AC), some means for regulating the frequency is needed. While constant-speed drives or converters are available, they add to the expense.

The storage problem must also be solved. What do you do when the wind stops blowing? There are several storage technologies. The most familiar is lead-acid batteries, which can be charged while the wind is blowing and then be used at a later time. Unfortunately, these can cost as much as the wind machine itself. Another alternative is to use pumped water or air--either pump water up into a reservoir and then let it fall to turn the turbines as needed (as is presently done with many conventional power plants), or use the wind machine to compress air that can be stored in tanks or natural caverns, and then fed into gas turbines as needed. Flywheel storage has also been suggested. In the future, one technique may be to use wind power to electrolyze water into hydrogen and oxygen and store the hydrogen for use as a fuel, or convert it to electricity in a fuel cell.

It may be that the storage problem can be circumvented. If enough wind machines covering a large area are linked together in a grid, the fluctuations can be averaged out to some extent and the difference made up by conventional plants or hydroelectric plants. An interesting future possibility will be to combine wind and direct solar generation of electricity for, to some extent, the winds tend to blow when the sun is not shining (at night and during storms).

In general, however, the components of a wind power generating system have relatively modest technical requirements by today's standards. Electrical generators, in fact, are available off-the-shelf for home use and it should be possible to engineer these designs into efficient large-scale systems. A major part of the potential for wind power in the U.S. can, in fact, be realized with current technology and with straightforward development.

WIND-GENERATED ELECTRICITY

In 1891, Paul La Cour started experimenting with electric wind generators in Askov, Denmark, and his basic design supplied that town with electricity until 1960, when hydroelectric power was introduced. The Soviets con-

structed a large scale (100 kw) wind electric plant in 1931 overlooking the Black Sea at Yalta, but like the Smith-Putnam machine, its bulk led to mechanical problems and the Soviets switched back to smaller plants (around 30 kw each) between 1935 and 1955.

At about the same time, the Jacobs Wind Electric Company in Minnesota was popularizing wind electric generators in the United States. Their machine, rated at 1500 watts capacity, generated 400 to 500 kw-hr per month and cost, with a full set of batteries, cables, and a 60 foot tower, $1000 at the factory. By 1957, when the REA shut his doors, Jacobs had sold $75 million worth of wind machines.

The only other innovation during those years was the 1.25 Mw wind electrical station built by Putnam at Grandpa's Knob. While Putnam's experiment proved that large-scale wind electric generation was possible, it was not until the 1970's that the idea was picked up again.

The increasing price of energy coupled with our growing dependence on foreign supplies has revived the Federal Government's interest in wind power. Its relatively low environmental impact, compared to fossil and nuclear plants has also made it popular with environmental spokesmen. As a result, the Federal funding of research and development has increased from $200,000 in 1973, to $1,500,000 in 1974, to an estimated $7,000,000 in 1975 and a requested $12,000,000 in 1976.

With some ERDA funding, NASA has built an experimental 100 kw wind turbine at Sandusky, Ohio. Mounted on a 100 foot tower, it has a rotor made of two blades, each 62½ feet long, the second largest windmill built in this country in 30 years. It will turn in 8 mph winds and reaches its rated capacity in winds of 18 mph or better.

At present the leading spokesman for wind power is William Heronemus ,a professor of engineering at the University of Massachusetts. Dr. Heronemus has identified several sites where large amounts of wind energy are available: the Great Plains, the eastern foothills of the Rocky Mountains, the Texas Gulf Coast, the Green and White Mountains of New England, the continental shelf of the northeastern United States, and the Aleutian Islands off the coast of California. One of his schemes calls for constructing a grid of wind machines at half mile or mile intervals throughout the Great Plains area. Such a system, he claims, could produce 190,000 Mw of installed electrical capacity, roughly half of the U.S. total in 1971. He has also proposed an offshore scheme in which the winds would be used to electrolyze water into hydrogen and oxygen. The hydrogen could then be piped to shore or brought in by refrigerated tankers.

It is generally thought that large-scale central power applications will call for straightforward "energy farms," each covered with a grid of identical wind turbines. This would take advantage of mass production economies and simplify R & D on basic units. Power densities of 40 Mw per square mile are thought possible in the Midwest with this approach, and should be entirely compatible with high-yield crop farming and cattle grazing. Because of the problem of wind power shutdown, a back-up fossil fuel plant may be needed to insure continued service.

Small-scale schemes may also continue to prove promising. A ten foot rotor could provide enough energy for an all-electric single family home in many parts of the U.S. Another option, too, would be to tie into, or remain tied into the existing utility line, switching to central-station power when the local generator is down or inadequate. Modern "homesteaders" are still finding wind power an economical alternative to having the nearest power company run lines out to their remote areas, and a number of companies are now producing wind electric generators designed for home use.

For all its antiquity, wind machine design is a new challenge to American engineers and several exotic designs have already appeared. Among these are the "Sailwing" (developed at Princeton and scheduled for production by Grumman Corp.) whose blade deforms in the wind and is therefore self-orienting. A prototype is already in operation in India. Also under development are several vertical axis designs which are not dependent on wind direction.

ENVIRONMENTAL PROBLEMS

Because wind machines are relatively passive "low technology" machines, there are no direct by-products or residues to dispose of and the secondary effects of their manufacture are not especially troublesome.

Their major drawback is land use. Although a single machine does not occupy much space, a giant grid of them complete with power lines would have aesthetic drawbacks, but wind harvesting should be compatible with other uses of the land such as pasturage and farming.

The efficiency of land use is also expected to be comparable to farm use. If "solar efficiency" is defined (for a large area windmill farm) as the ratio of power output from the windmills to the solar-power incident on the land they occupy, it is estimated that efficiencies of about 5 percent are possible in

the Great Plains area. Photosynthetic efficiency of growing plants is about 1 percent.

If really large-scale use becomes a reality, there will be questions to answer about possible effects on weather caused by the removal of large amounts of kinetic energy. In general however, wind energy, like other forms of solar energy, seems to be environmentally benign.

OTHER PROBLEMS

Wind power development has been held back so far by economic considerations. Proponents insist, however, that once development is past the pilot plant stage and components are mass produced, wind power generators will be competitive with fossil fuel and nuclear plants. A recent comparison estimates the cost of building wind power generating plants at $150-$200 (in 1974 dollars) per installed kilowatt. The wind power system suffers because it is at full capacity only 25 percent of the time on the average, while coal and nuclear operate at 50 to 60 percent load factors. However, the low load factor of the wind machine is compensated for by low maintenance and zero fuel costs. The total cost of its electric energy is projected at 2 or 2½ cents per kw-hr—about the present average cost of electricity produced by conventional power plants. Given the early stage of development, this is an encouraging picture.

SUMMARY

The most telling measure of the increasing importance attached to wind power is the funding level which has risen from $200,00 in 1973 to a (requested) $12 million in 1976. To the wind power enthusiasts, however, this is not enough They argue that wind power is in fact an old and proven system far more worthy of accelerated development than the breeder reactor (for which the 1976 developmental support is $475 million).

What does arise clearly, in spite of the controversy, is the real potential of wind power as a supplementary source of electricity. The energy is there, and we have sufficient technological knowhow to tap it. No one questions that the technology can be improved and that there will be problems to overcome. The task of building a large grid of wind machines is, however, one that could be accomplished relatively inexpensively and, in contrast to other power plants, quickly. (The 1.25 Mw generator on Grandpa's Knob was constructed in 19 months.) If the priority and support is forthcoming we canbegin to define the windmill's new role before the decade of the 70's is over.

REFERENCES

1. "Wind Power Now," David R. Inglis, Bulletin of the Atomic Scientists 31 (8): 20-26, October 1975.
2. "Wind Power: How New Technology is Harnessing an Age Old Energy Source," Popular Science 205:54-9 +, July 1974.
3. "Pulling Power Out of Thin Air," G. Soucie, Audobon 76: 81-8, May 1974.
4. "Can We Harness the Wind?", R. Hamilton, National Geographic 148: 812-29, December 1975.
5. "Energy from the Winds" (pp. 513-551) in Energy for Survival, Wilson Clark (New York:Doubleday) 1974.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

LECTURE NOTES

FOR A DISCUSSION OF SEVERAL ASPECTS OF NUCLEAR ENERGY, REFER TO FACT SHEET # 12, #13, #14. PRIMARILY, NUCLEAR FISSION, NUCLEAR FUSION, AND BREEDER REACTORS AND THE ADVANTAGES & DISADVANTAGES OF EACH. TO SUMMARIZE SOME OF THE MATERIAL IN THE FACT SHEETS REFER TO VISUALS #6, #7 AND THE FOLLOWING.

THE MAJOR ATTRACTION OF NUCLEAR ENERGY IS BASED ON EINSTEIN'S EQUATION: $E = MC^2$ WHERE E = ENERGY IN JOULES, M = MASS IN GRAMS, AND C^2 = SPEED OF LIGHT IN METERS (300,000,000) SQUARED OR 90,000,000,000,000 METERS. MULTIPLYING THIS FIGURE BY I GRAM WE GET 9 X 10 TO THE THIRTEENTH POWER JOULES OF ENERGY. TO PUT IT ANOTHER WAY, APPROXIMATELY A TON OF MATTER, IF IT COULD ALL BE CONVERTED TO ENERGY WOULD EQUAL THE ENTIRE U. S. CONSUMPTION OF ENERGY IN 1970. IT IS NOT POSSIBLE TO CONVERT ALL MATTER TO ENERGY, BUT A RARE FORM OF NATURES HEAVIEST ELEMENT URANIUM 235 CAN BE CONVERTED AT A RATE OF ABOUT .1% STILL VERY SUBSTANTIAL. THE REMAINDER OF THE MASS BREAKS INTO 2 SMALLER ELEMENTS IN A PROCESS CALLED FISSION AND BECOMES KRYPTON AND BARIUM. THERE ARE ALSO UP TO 3 HIGH ENERGY NEUTRONS WHICH MAY STRIKE OTHER U - 235 ATOMS AND CAUSE THEM TO BREAK UP IN WHAT IS CALLED A CHAIN REACTION WHICH IS SELF SUSTAINING DEPENDING UPON, AMONG OTHER THINGS, THE CONCENTRATION OF U - 235 IN THE FUEL MIXTURE. AS INDICATED PREVIOUSLY, U - 235 IS RARE, AND MOST OF THE FUEL MIXTURE IS U - 238 WHICH FORTUNATELY OR UNFORTUNATELY, DEPENDING ON YOUR POINT OF VIEW, DOES NOT BREAK UP AND CREATE ENERGY WHEN STRUCK BY A NEUTRON, BUT FUSES WITH IT TO FORM U - 239, WHICH SPONTANEOUSLY CHANGES TO PLUTONIUM 239. SEE BOTTOM OF VISUAL # 6. PLUTONIUM CAN BE REPROCESSED TO BECOME FUEL FOR ANOTHER REACTOR, BUT UNFORTUNATELY ONCE IT IS CONCENTRATED CAN BE STOLEN BY TERRORISTS TO MAKE BOMBS. IT AS ALSO BEEN CALLED THE MOST TOXIC SUBSTANCE ON EARTH. SEE FACT SHEETS FOR MORE PROS AND CONS OF FISSION POWER.

ALMOST NO ONE ARGUES AGAINST NUCLEAR FUSION AS A CLEAN SOURCE OF POWER. IF CERTAIN FORMS OF HYDROGEN CALLED ISOTOPES, THE PREFERED ONES ARE DEUTERIUM AND TRITIUM, CAN BE FORCED TO FUSE TOGETHER AND FORM HELIUM, TREMENDOUS AMOUNTS OF ENERGY WILL BE RELEASED WITH ALMOST NO RADIOACTIVE CONTAMINATION. SEE TOP OF VISUAL # 7. UNFORTUNATELY TRITIUM AND DEUTERIUM MUST BE COMPRESSED ABOUT 10,000 TIMES AND RAISED TO ABOUT 40 MILLION DEGREES CELSIUS, A FEAT WHICH HAS NOT YET BEEN ACHIEVED ON A USEABEL SCALE. WHEN FUSION IS PERFECTED THE ENERGY CRISIS WILL BE ESSENTIALLY OVER. SEE CENTER PART OF VISUAL #7 FOR JUST ONE OF MANY ATTEMPTS AT FUSION - LASER FUSION. IT USES AND EXTREMELY HIGH POWER PULSE LASER AND A TINY PELLET OF GLASS ENCAPSULATED TRITIUM/DEUTERIUM MIXTURE. THE PELLET IS INJECTED INTO A SPECIAL CHAMBER AND IS STRUCK BY A PULSE FROM THE LASER. THE SECRET OF THE LASERS FANTASTIC POWER IS THE POWER EQUATION. RECALL FROM UNIT ONE, THAT POWER IS WORK DIVIDED BY TIME. IF THE LASER CONTAINS ONLY ONE JOULE OF ENERGY AND THE PULSE OR FLASH LASTED FOR ONE SECOND , THEN ONE WATT OF POWER WOULD BEEN BROUGHT TO BEAR ON THE PELLET. BUT IF THE PULSE LASTS ONLY A BILLIONTH OF A SECOND THEN THE PELLET IS TEMPORARILY EXPOSED TO A BILLION WATTS OF POWER! SEE BOTTOM OF VISUAL #7.. IMAGINE, A BILLION WATTS OF POWER FOCUSED ON AN AREA LESS THAN 1/10 THE SIZE OF A PINHEAD! STILL THIS IS NOT ENOUGH TO CAUSE THE ISOTOPES TO FUSE. IT WILL TAKE ABOUT A MILLION JOULE LASER DUMPING ITS ENERGY ON THE PELLET IN A BILLIONTH OF A SECOND, THE EQUIVALENT OF 1.3 TRILLION HORSEPOWER. CURRENT LASERS CAN ONLY PRODUCE SEVERAL THOUSAND JOULES ON ENERGY.

VISUAL # 6

$E = MC^2$

JOULES = GRAMS X METERS (SPEED OF LIGHT)

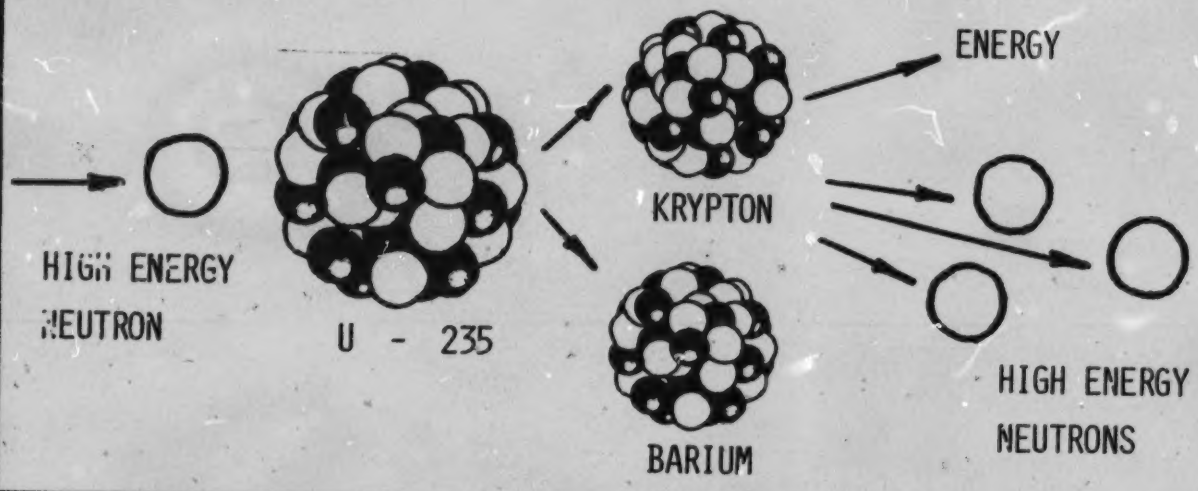
THUS, 1 GRAM OF MATTER = 90000000000000 JOULES OF ENERGY

OR:

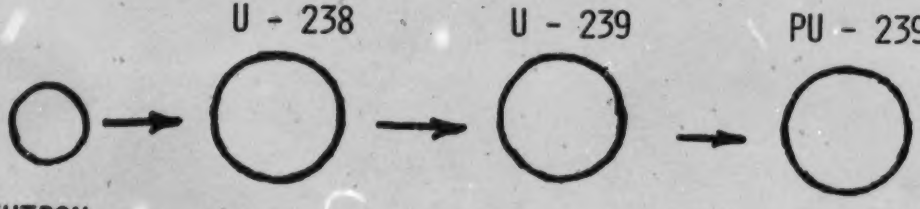
1 TON OF MATTER = APPROXIMATELY ALL OF THE ENERGY USED IN U.S. IN 1970

UNFORTUNATELY, MOST MATTER CANNOT EASILY BE CONVERTED TO ENERGY. HOWEVER ABOUT 1/10 OF 1 % OF URANIUM 235 CAN BE, AND ACCORDING TO THE ABOVE EQUATION, THIS IS A VERY SIGNIFICANT AMOUNT.

FISSION OF URANIUM 235

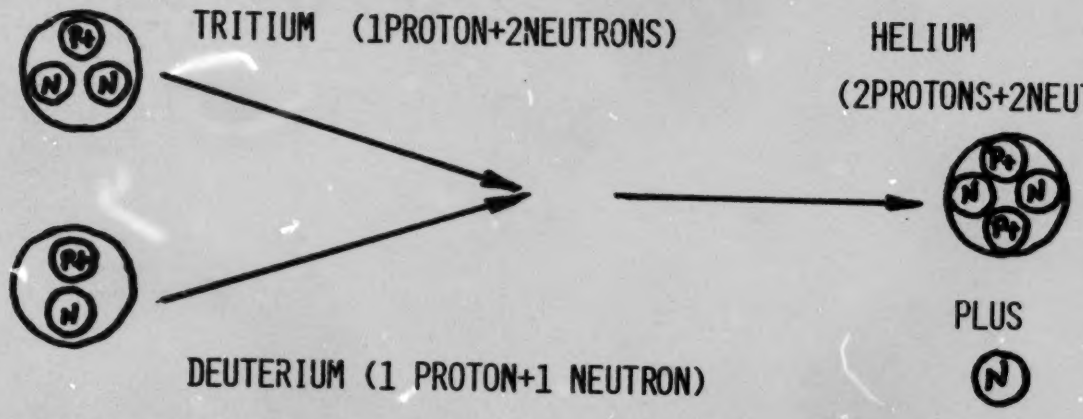


FUSION OF U - 238 TO PU - 239

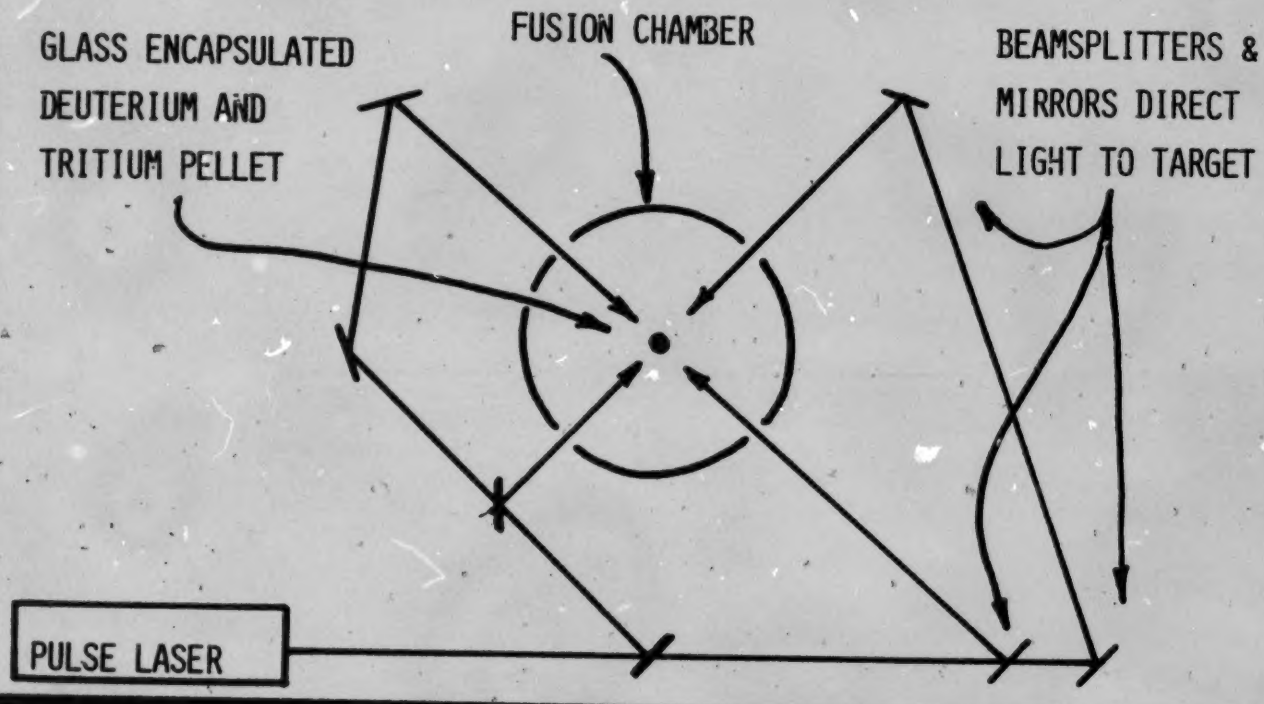


FROM U - 235 + U - 238 = U - 239 WHICH CHANGES TO PLUTONIUM 239

VISUAL # 7



FUSION TAKES PLACE AT 40 MILLION DEGREES CELSIUS AND A VOLUME COMPRESSION OF 10,000 TIMES


GLASS ENCAPSULATED DEUTERIUM AND TRITIUM PELLET
FUSION CHAMBER
BEAMSPLITTERS & MIRRORS DIRECT LIGHT TO TARGET
PULSE LASER

$$\text{POWER} = \frac{\text{WORK}}{\text{TIME}}$$

$$1 \text{ WATT} = \frac{1 \text{ JOULE}}{1 \text{ SEC.}}$$

$$1 \text{ BILLION WATTS} = \frac{1 \text{ JOULE}}{1 \text{ BILLIONTH OF SEC.}}$$

12. CONVENTIONAL REACTORS

John M. Fowler

FACTSHEET

United States Department of Energy

Assistant Secretary for Intergovernmental and Institutional Relations

Education Programs Division

INTRODUCTION

It could be argued that conventional nuclear reactors do not belong on a list of alternate energy sources. As of November 1976, 64 were contributing 45,500 Mw of generating capacity, generating 8 percent of the Nation's electrical power. This technology was already understood in principle by the early 1940's and the first operating commercial plant went on line in 1957.

We have included a Fact Sheet on these reactors, however, for several reasons. They are still a relatively new contributor to the energy mix and are expected by their proponents to play a major energy role in the next decade, producing as much as 20 percent of our electrical energy by 1985. They are also far and away the most controversial component of the energy mix, bitterly opposed by some scientists and a vocal segment of the public, and just as strongly championed by different groups. Perhaps more than any other energy option, they need a Fact Sheet.

The very reasons, however, that call for a Fact Sheet make the production of one difficult. In spite of its early beginnings, we really have little experience with this technology and the questions raised are broad; extending into ethical, economic, and political areas. Facts are difficult to identify and objectivity is difficult to achieve. It is, however, necessary to make the effort.

We are dealing, in this Fact Sheet, with "converter reactors." Most of our present reactors are of this type. They convert fissionable fuel into energy and are thus distinguished from the "breeder reactors" which can produce new fuel along with electrical power. We describe breeder reactors in a separate Fact Sheet (#13).

RESOURCES

Present day converter reactors obtain their energy from the fissioning of a rare form of uranium, uranium 235.* This "isotope" (see footnote) makes up less than 1 percent (actually 0.7 percent) of common uranium ore, most of which is U^{238}.

Uranium 235 releases energy when the nucleus, the core of the atom, undergoes fission - splits into two fragments. The amount of energy

---

* U^{235} is the accepted symbol for the isotope of uranium which has 235 particles in its nucleus. It is thus distinguished from U^{238}, another isotope, chemically identical, but possessing different nuclear properties. For further discussion, see Glossary Fact Sheet #18.

This material was produced by the National Teachers Association under contract with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

released is large. The fissioning of one pound of uranium could produce 9 billion Calories of energy, 3 million times the energy released in the burning of a pound of coal. The actual comparison, as we shall see, is much less dramatic.

Uranium occurs in small amounts in most rock. To be mined, however, the deposit must be concentrated. Commercial ore, on the average, contains 4 or 5 pounds of uranium oxide, U_3O_8 (the commonly occuring uranium compound). Of these 4 or 5 pounds, only 0.02 to 0.03 lbs are the sought-after uranium 235.

Uranium fuel production begins with a search for ore that is rich enough to mine and a lot of rock and dirt is moved in the process. The raw ore is then "milled," concentrated to a product called "yellowcake" which is 80 percent U_3O_8. If a 1000 Mw reactor were to operate at 70 percent efficiency, it would use 130 tons of yellowcake per year. (It uses 170 tons per year at 80 percent efficiency.)

Resource estimates are given in terms of tons of yellowcake and are distinguished by the production cost in dollars per pound. The latest estimate of "reserves" (identified resources) and potential resources given by the Energy Research and Development Administration (ERDA) are for 430,000 tons of reserves available at under $15 per pound and 640,000 tons of reserves plus 140,000 tons of "by product" U_3O_8 at under $30 per pound. (The "by product" is uranium that could be produced during the mining and refining of other materials.) In the "potential" category (not yet discovered and developed) are an estimated 2,050,000 tons at under $15 per pound and 3,700,000 tons at under $30 per pound. (A complete summary of the uranium resources is given in the Breeder Fact Sheet, #13.)

Converted to Calories by their theoretical energy content, these tons of uranium represent an enormous amount of energy. In fact, however, reactors use only a small percentage of their fuel. A practical assessment of the energy equivalent of these resources can be obtained using the 130 tons annual requirement of yellowcake in a 1000 Mw reactor. We can calculate, for instance, that the 45,500 Mw of reactors presently operating will use up the 420,000 tons of $15 per pound reserves in 73 years.

The suggestion of this calculation, that the resource lifetime of uranium may turn out to be comparable to that of oil or natural gas, is supported by studies which take into account the expected nuclear growth. ERDA estimates that all of the $30 per pound reserves will be used up during the 30 year operating lifetime of the reactors presently in operation, under construction, or on order (a total of about 235,000 Mw generating capacity). Even this estimate counts on the recycling of plutonium;* if this process does not become a part of the fuel cycle, then the under $30 reserves will only fuel about half this amount of generating capacity.

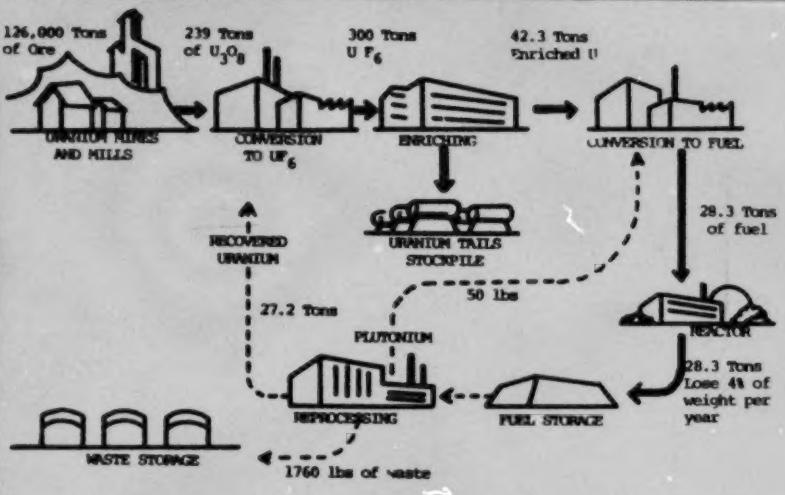
We have considered, so far, only the reserves. If the potential resources are as large as projected, the lifetime becomes longer. The whole subject of uranium resources is, in fact, a controversial one, and one which enters strongly into the controversy over the breeder reactor. We will not deal further with it here, but refer the reader to Fact Sheet #13. A fair summary, however, seems to be that uranium supplies are sufficient to fuel the planned reactor program into the next century, but that without new supplies or a new technology (like the breeder reactor) it will provide only temporary relief to our energy shortage.

TECHNOLOGY

Because a full understanding of nuclear reactors requires considerable knowledge of their inner workings, we will not be able to afford space in this Fact Sheet for a detailed discussion and refer interested readers to the bibliography for further reading. We will confine this section to an overall view of the fuel cycle - the step-by-step movement of uranium from mine to reactor, etc. Some additional technological details will be developed in the section on Safety.

The fuel cycle: The accompanying illustration shows the most important steps in the production and utilization of uranium. Since the raw ore only contains a small percentage (2 or 3%) of uranium, 100,000 or more tons of ore must be mined to provide the 150 to 200 tons (239 tons in the diagram) of uranium oxide, which is about the annual requirement of a 1000 Mw nuclear reactor. The ore is refined and concentrated in the milling operation. It then goes through a conversion to a gas, uranium hexafluoride, which is the form in which enrichment takes place. In the enrichment plant the amount of U^{235} is increased from the original 0.7 percent to 3 or 4 percent. This enriched uranium is then assembled into the fuel elements while the uranium which has been depleted in U^{235} (which is largely U^{238}) is stored. (It is this stockpile that the breeder reactor may draw upon.)

* Plutonium, Pu^{239}, is a fossil fuel which is made from U^{238} in the reactor fuel rods during power production. It can be removed from the used fuel rods and be used as a reactor fuel.



THE LIGHT WATER REACTOR NUCLEAR FUEL CYCLE
(Numbers are for 1000 Mw reactor)

Capital is but one of the items that determine the final costs per kilowatt-hour of electrical energy. The operating and maintenance costs and fuel costs must also be figured in. If the costs of interest is placed somewhere in the future, 1986 for instance, it is very difficult to produce a projection that everyone agrees with. There are too many variables. We show in the table below a report from the atomic industry in which representative 1975 costs and projections of costs in 1985 are given. In this comparison, the nuclear reactor produces the least expensive electricity.

After a year's operation the fuel is removed. The present practice is to replace one third of the reactor fuel each year. The initial loading of the 1000 Mw reactor would therefore take three times the amounts of yellowcake, uranium, etc. shown in the illustration.

The reprocessing steps shown are not presently in operation but may eventually return uranium 235 and plutonium 239 to the fuel cycle.

The other flow out of the reprocessing plant is of radioactive waste materials which require long term storage. We will refer back to this fuel cycle in our later comments on safety and waste disposal. We will, however, next discuss the important and uncertain economics of nuclear power.

ECONOMICS

In 1970 and 1971, the capital costs of generating plants were commonly quoted as $250 per kilowatt for nuclear plants, and $200 per kilowatt for coal-fired plants. In 1975, Southern California Edison estimated nuclear plants to be delivered 10 years from now at $940 per kilowatt and coal-fired plants at $860 per kilowatt. While these latter costs (which mean that a 1000 Mw plant now requires almost a billion dollars to build) may not be exact national averages, they do correctly reflect the remarkable inflation which has taken place.

This overall increase has many causes: wages have increased, the duration of the construction period has lengthened, materials are more expensive, new safety devices and anti-pollution equipment is now required, but a major factor is the cost of the money itself, the large increase in interest rates.

These figures, and other like them, however, are vigorously questioned by nuclear power opponents. There is not even agreement on the historical data, let alone on the projections.

Economic Comparison of 2 - 100 Mw Generating Units (Mills/KWHR)

		Oil	Coal-fired with Scrubbers	Coal-fired with Tall Stacks	Nuclear
Capital	1975	4.1	6.1	4.5	9.5
	1985	14.7	20.8	18.1	27.4
Fuel	1975	20.9	13.3	12.3	2.9
	1985	32.4	25.0	22.7	6.9
Operating and Maintenance	1975	1.2	2.7	1.3	1.5
	1985	2.4	5.0	2.6	2.5
Total	1975	26.2	22.1	18.1	13.9
	1985	49.5	50.8	43.4	36.8

Source: V.S. Boyer, Philadelphia Electric Co.

The 1975 data in the table above, for instance, show nuclear-produced electricity averaging 13.9 mills per kw-hr and coal-produced electricity (without scrubbers) averaging 18.1. The overall industry averages reported in Electrical World (November 15, 1975) for a two year period are nuclear, 18 mills, coal, 13.8 mills. It seems to make a difference whether only those plants which have both nuclear and coal-fired plants (as in Boyer's data shown in the table) are surveyed or whether total industry data is used.

The projections are even more open to controversy as values for interest rates, inflation, fuel costs, etc. must all be assumed. Much of the controversy has centered on the selection of an appropriate "capacity factor". This number measures the ratio of the electrical energy actually produced to the total rated capacity of the plant. It has turned out, so far, that the larger plants, those over 800 or 1000 Mw, are less reliable whether they are coal-fired or nuclear. If a lower capacity factor is assumed for nuclear, the mills per kw-hr nuclear advantage weakens.

We are here skirting the edges of a violent and unresolved controversy. We will not go more deeply into it, but suggest further reading in the brief bibliography at the end of this Fact Sheet. A reasonably objective summary of the economic picture is the following. Nuclear and coal-fired plants are economically competitive. Which one has the advantage depends on many factors including air pollution control requirements, cost of fuel, cost of money, etc. Probably the only thing that we can be sure of is that the cost of the electric energy produced by either plant will increase rapidly over the next decade.

ENVIRONMENTAL EFFECTS

Nuclear reactors, if they come to dominate electric power production, will ease several of our perplexing environmental problems. They do not produce the air pollutants presently associated with coal or other fossil fuel plants. The amount of ore to be mined, 100,000 tons of uranium vs. 2,500,000 tons of coal per year for a 1000 Mw plant, would help to reduce the worry over strip mining. Reactors, however, have their own environmental impact.

We will discuss two types. The more or less "conventional" pollution problems posed by the radioactivity which is a by-product of the fission process and a broader set of hazards which we will deal with under the title Safety.

Radioactive Pollution: The fission fragments are radioactive - they emit energetic particles or radiation which can penetrate tissue or other matter. The amount of radioactive material which accumulates during a year's operation of a reactor is enormous. As an example, if half the strontium 90 (one of the more hazardous radioactive waste products) which is accumulated in one year of operation by a 1000 Mw plant, were to be sprinkled over the country, it could contaminate all the fresh water runoff in the continental U.S. to six times the official "Maximum Permissible Concentration" of that contaminant.

Such selective deposition is not possible. Radioactive pollution is, of course, rigorously controlled at the reactors. The regulatory guidelines are quite strict and a person could, in fact, quite safely (as far as routine emission of radioactivity is concerned) live right at the plant boundary line. The exposure caused by the routine operation of even the several hundred reactors projected for the future will still be small compared to other sources of radiation exposure.

At present the control over releases from reprocessing plants is not as satisfactory. There is only one plant (at West Valley, N.Y.) and it has not been operating at full capacity (and is presently closed). During some years releases of some gaseous radioactive products have been as large as 20 percent or so of the allowed maximum. It is quite clear that more stringent safety measures are needed here as more and larger reprocessing plants go into operation.

Radioactive Waste: The left-overs, the "ashes" of the conversion process, are not only radioactive, but remain so for a long time. The crucial parameter of a radioactive substance is its "half life", the time during which half of a sample of the material will "decay", or change into something else. Radioactive species with short half lives are intensely dangerous for short times, while longer half lives mean that the radiation is less intense, and is spread out over longer times.

In assessing the danger to man, one has to consider, in addition to the half life, the biological properties of a contaminant. Several of the fission products, notably radioactive forms of strontium and cesium (Sr^{90} and Ca^{137}) have dangerous combinations of half lives (about 30 years) and biological properties and so must be kept completely out of the ecosystem for hundreds of years.

It is this necessity for complete isolation that is the challenge of radioactive waste disposal and which makes the discussion so often acrimonious. Questions are raised which are both ethical and technological. We are, in effect, leaving this material to our descendants. It will have to be stored and monitored for several generations. There is no precedent in our history for such a task.

The technological solution seems to be easier. One plan which is being considered calls for the flash drying of the high level liquid waste to a ceramic material with a large reduction in volume. These "hot rocks" would then be stored for at least a few hundred years in some dry and geologically isolated spot - a salt mine, for instance.

Since the annual amount of dried high level waste from a 1000 Mw plant occupies only about 60 cubic feet of space (a cube a little less than 4 feet on a side), the requirements of storage space will not be overwhelming. (The waste cannot, of course, be stored this compactly because it is physically hot as well as radioactively "hot".)

The weakness of the technological solution, constantly pointed to by the nuclear critics, is that no agreed to official plan presently exists and the waste is not as yet being processed in this way. It is piling up rapidly in temporary storage. The resolution of this waste disposal problem must come quickly if the reactor program is to grow at its projected rate. The problem must be faced, however, even without electrical generation because of the waste already generated in weapons production.

SAFETY

The most emotion charged issue in the nuclear controversy is the safety issue. There are actually three parts to the safety question: the safety of the transport of radioactive fuels and waste material, the safety of nuclear fuels from the danger of hijacking by would-be bomb makers, and the safety of nuclear plants themselves.

We can deal with the first part rather swiftly. Although there is a growing concern over the increasing volume of radioactive materials on our roads and railways - 52 shipments per day by 1980 - the great care exercised so far has prevented serious accidents and this problem seems manageable.

The danger from hijackers seems more threatening and it is a danger that may grow if we institute plutonium recycling and the breeder program. We discuss this problem in Fact Sheet #13.

Nuclear Accidents: The focus of much anti-nuclear concern is on the danger of an accident at a reactor which will release some of its deadly contents to its surroundings. It is not a nuclear explosion which is feared, the U^{235} is not present in sufficient concentration to make a "critical mass" and a runaway chain reaction. The perceived greatest danger is that a reactor will, for some reason, lose its cooling water, melt down and either melt through its containment or fracture it by a steam explosion. If this happens, the lethal contents may be released to the countryside. As a background to the discussion of accidents we need a few facts about the reactor control mechanisms.

119

The fission reaction which produces the energy in the nuclear power plant is a self-sustaining one. The nucleus (uranium 235, in most cases) absorbs a neutron and undergoes fission. Energy is released along with additional neutrons, 2.5 on the average (which means sometimes 1, sometimes 2 or 3). These neutrons sustain the reaction. At least one must be used to cause another fission; but if two fissions are caused, a chain reaction builds up.

Control is obtained through a series of "control rods," similar to the fuel rods which make up the reactor core and interspaced among them. These are filled with a neutron absorbing material and the number of neutrons available for fission is regulated by moving them in and out of the core. The reactor can be shut down, or "scrammed," by running all the control rods into the core.

The reactor remains very hot for sometime after shutdown and cooling is thus extremely important. Without a cooling system, a reactor would melt in less than a minute. To prevent this there is, in addition to the regular cooling system (the water which carries the heat energy to the steam generator), a back up "emergency core cooling system" designed to dump an enormous amount of water into the reactor if the regular system fails. Much of the controversy over reactor safety has focused on this emergency system which has never been fully tested.

In general, we can say that reactors are designed with several layers of safety systems and that their record so far is impressive. There have been no radiation related fatalities or injuries at a commercial reactor. It is, in fact, this very lack of experience which contributes to the uncertainty some reactor opponents feel.

It is extremely difficult to arrive at a consensus assessment of the accident hazard. Nuclear proponents point to the record of almost 1000 reactor years* of world wide commercial operation without fatal accidents and to studies which give a probability of 1 in 100,000,000 per reactor year that an accident causing 1200 or more deaths will occur.

The critics question both the probability calculations and their implications. They point to the assumptions and estimates in the calculation and the lack of actual experience. They enumerate the many minor accidents which have occurred because of human and equipment malfunction not foreseen by regulations and elaborate safety systems. They also point out that 1000 reactors operating for ten years lowers the safety margin offered by the odds to 1 in 10,000.

* A reactor year is one year's operation of one reactor.

The prudent course of action would seem to be to recognize the great danger of this form of energy conversion, to keep reactors away from the cities, continue to enforce stringent safety and security regulations and to look to new ways to make them even more safe. A long term solution espoused by many is to step up the search for alternate energy sources so that this dangerous, but seemingly necessary experiment can be terminated as soon as possible.

SUMMARY

The irresistible analogy that springs to mind when discussing nuclear energy is the genie released from the lamp. It is a genie which offers great power at a time when our traditional sources of energy and power are disappearing. It is a genie needing rigorous control.

The genie has been released, however, and the 45,500 Mw of nuclear generating capacity available at the end of 1976 may grow to 200,000 or 300,000 Mw by 1990. But the road to a nuclear future is not clear of barriers. More uranium will have to be found or the second generation, the breeder reators, will have to provide the fuel. The ultimate cost comparison with coal as an energy source is still uncertain. It is clear that the capital requirements now at $1 billion per 1000 Mw plant are enormous. And there are the questions of hazards we have discussed.

There seems to be no question that the Federal Government's support of conventional reactors continues strong. There were $522 million in the FY 76 ERDA budget for fission and expenditures of $709 million are projected for FY 77. These sums included support of the breeder reactor, and the Administration's new energy program announced on April 20, 1977, reduces support of the breeder by about $200 million. In addition to this basic support there were $163 million in FY 76 and $282 million projected for FY 77 for R&D on the nuclear fuel cycle and safeguards. ERDA projects 400 to 600, 1000 Mw nuclear generating plants in existence by the year 2000 and counts on them for about 36% of the installed electrical capacity for that year. The next ten years, however, will be the crucial years during which the answers to economic, environmental, and resource questions will shape the actual future of this new form of energy.

BIBLIOGRAPHY

1. Nuclear Power Plants, R. L. Lyerly and Walter Mitchell III, revised edition (Washington: USAEC) 1973 (Available from: ERDA, Technical Information Center, Oak Ridge, Tenn. 37830).

2. The Nuclear Fuel Cycle, A Survey of the Health, Environmental, and National Security Effects of Nuclear Power, prepared by the Union of Concerned Scientists (Cambridge, Mass.: MIT Press) 1975.

3. Nuclear Fuel Cycle, A Report by the Fuel Cycle Task Force, USERDA, (ERDA-33) March 1975.

4. Nuclear Energy: Its Physics and Its Social Challenge, David Inglis (Reading, Mass.: Addison-Wesley) 1973.

5. "Nuclear Energy: Paradise Deferred," Saturday Review, January 22, 1977, a special issue of seven articles on nuclear energy.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

Printed 1977
Reprinted September 1978

LECTURE NOTES

FACTSHEET

United States Department of Energy

Assistant Secretary for Intergovernmental and Institutional Relations

Education Programs Division

13. BREEDER REACTORS

John M. Fowler

INTRODUCTION

To a world faced with escalating fuel prices and rapidly shrinking fuel reserves, a device which produces electric power and creates, at the same time, more fuel than it burns should seem a godsend. After the initial skepticism of those who know about the Law of Conservation of Energy is explained away, such a machine, one would think, would be welcomed with rejoicing. There is, in fact, such a machine, but its welcome has been mixed.

The "Breeder Reactor" is a "second generation" or advanced nuclear fission reactor. It will obtain energy, as does its existing predecessor, the nuclear converter reactor*, from the fission reaction - the splitting of a fissionable element such as the heavy nucleus uranium or plutonium. The breeder reactor program, therefore, shares the same suspicion that has dogged the rest of the nuclear program. It has its own difficulties.

The "magic" of the breeder is, in principle, fairly simple to understand. To produce energy, a fissionable nucleus is caused to split, releasing energy and at the same time two or three neutrons. One of these neutrons in turn must cause another fission to continue the chain reaction which provides the power. The other neutrons can be used to create fissionable nuclei out of material that is not otherwise usable as nuclear fuel, in particular it can create useful fuel out of nonfissionable uranium or thorium. There is no controversy over this. If more than one fissionable nucleus is created this way for each one that is split, then the reactor is called a "breeder" for it "breeds" more fuel than it uses.

The controversy which does exist falls into the same categories - economic, environmental, safety - as does the controversy over the conventional reactor. The arguments put forward in each category, however, are quite different. In the following sections we will briefly describe the way in which the breeder works and examine the contrasting statements and opinions on its economic feasibility and necessity, its effects on the environment and its safety related issues.

RESOURCES

A good bit of the controversy which surrounds the breeder reactor concerns the amount of resources. As explained in Fact Sheet #12, Conventional Reactors, this nation's known resources ("reserves") of inexpensive uranium are not infinite or even very large. The latest resource estimate from ERDA puts the presently developed uranium "reserves" which can be produced at under $30 per pound, at 820,000 tons. If the fuel is recycled (it is not at present) these reserves will be used up during the 30 year average lifetime of reactors currently operating, under construction, on order, or announced - a total of about 231,000 Mw (as of April 1, 1977) of electrical generating capacity. Without fuel recycle (see Fact Sheet #12), the 820,000 tons of reserves will only fuel about 60% of that generating capacity (140,000 Mw). If we were to develop and mine no more uranium than these reserves (an unlikely prospect), the nuclear age would be a short one.

These estimates deal with uranium 235, the rare form of uranium which is needed to fuel the conventional reactors. It makes up only 0.7% of the

* See Fact Sheet #12 for a description of conventional nuclear reactors.

This material was produced by the National Teachers Association under contract with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

uranium in uranium ore. Uranium 238 accounts for almost all the rest. What the breeder reactor does is to convert U^{238} into plutonium and thus uses almost all of the energy available in the uranium fuel instead of the 1 to 2 percent of conventional reactors.

The ERDA estimate of the reserve of uranium for breeder use, as given in their 1976 report "A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future," (referred to usually as ERDA 76-1) is 130,000 Q*, or enough, at 1975 levels of consumption, to provide all this country's energy needs for about 1800 years. The magic, however, is even more astounding. Because the breeder reactor uses fuel so efficiently, uranium price is no longer a major contributor to the price of electricity. This opens up more dilute and higher-priced ores to consideration.

There is no argument between the pro and anti-breeder camps about the breeder's ability to greatly magnify the energy potential of the U.S. uranium resources. The important questions are: how quickly will the U.S. resources of inexpensive uranium be used up; how much will the price of electricity increase? The answers to these will go a long way toward determining the breeder's economic viability.

This argument can become quite complicated; it depends, for instance, on whether the spent fuel is reprocessed and the uranium and plutonium recycled, and on the amount of uranium 235 left in the "tails," discarded from the enrichment process. It also depends importantly on comparisons of capital costs and on assumed electrical demand and the fraction of that demand which is to be nuclear. For more detail we give the complete ERDA uranium estimate.

U.S. URANIUM RESOURCES
January 1, 1977

$/lb. U_3O_8 Cost Category	Reserves	Potential: Probable	Possible	Speculative	Total
$10	250,000	275,000	115,000	100,000	740,000
$10-15 Increment	160,000	310,000	375,000	90,000	935,000
$15	410,000	585,000	490,000	190,000	1,675,000
$15-30 Increment	270,000	505,000	630,000	290,000	1,695,000
$30	680,000	1,090,000	1,120,000	480,000	3,370,000
$30-50 Increment	160,000	280,000	290,000	70,000	800,000
$50	840,000	1,370,000	1,410,000	550,000	4,170,000
By-Product 1975-2000a/	140,000	---	---	---	140,000
	980,000	1,370,000	1,410,000	550,000	4,110,000

a/ By-Product of phosphate and copper production.

The total amount, including less certain categories such as "possible" and "speculative," is for 3,500,000 tons - almost 4 times the "reserve" figure. In a recent ERDA study, the cumulative uranium requirement, from 1976 to 2000, (assuming fuel recycling) is 1 million tons; without recycling it is 1.3 million tons. Although this is half again as much as the reserves, it is only about one-third of the potential resources. Other studies have produced essentially similiar results.

It seems fair to say, in summary of the resource debate, that the potential inexpensive uranium resources are sufficient to take a healthy electric industry (5.2 percent per year growth) with a healthy nuclear component (about 40 percent of the total generating capacity in 2000) to the year 2000 and beyond, to perhaps 2020 or 2040. The resources will last even longer if electrical and nuclear growth is lower than projected. It should be noted, however, that if this growth occurs, all of the estimated economically available uranium resources would be committed by the mid-1990's and no more plants could be assured of fuel supply after that time. If the nuclear component of electrical generation is to continue to grow in the next century, development of the breeder will be necessary.

The extreme reactions to this summary would be the following: on the one hand, higher electric growth and a larger nuclear commitment would be coupled with pessimism over the accuracy of the "potential resources" estimate to argue for the breeder's necessity and its early development. On the other hand, conservation-aided reduction in electrical growth, limitation of nuclear growth and arguments that the potential resource is even larger would remove resource restrictions as an argument for early development of the breeder.

TECHNOLOGY

We have briefly surveyed nuclear fission technology in Fact Sheet #12. In this section we will limit our description to techniques unique to the breeder reactor.

The "breeding" of nuclear fuel consists of converting a non-fissionable nucleus such as uranium 238 into a fissionable nucleus such as plutonium 239. The process is as follows:

In the fissioning of uranium 235, several neutrons are released along with energy and the radioactive fission products. There are, on the average, about 2.5 neutrons released per fission (which means, of course, sometimes 1, more often 2 or 3, etc., since a fraction of a neutron has no meaning). One of these neutrons is needed to maintain the power-producing chain reaction. The others can be used to form new fissile fuel. The process, in nuclear notation is: $_Z$

* A "Q" is 10^{15} Btu - See Fact Sheet #18.

LECTURE NOTES

$$U^{238} + n \rightarrow U^{239} \xrightarrow{\text{rapid decay}} Np^{239} \xrightarrow{\text{rapid decay}} Pu^{239} \xrightarrow{\text{slow decay}}$$

(Rapid decay means that the change takes place in a time less than a month, while a slow decay takes hundreds or thousands of years. The letter "n" means a neutron.)

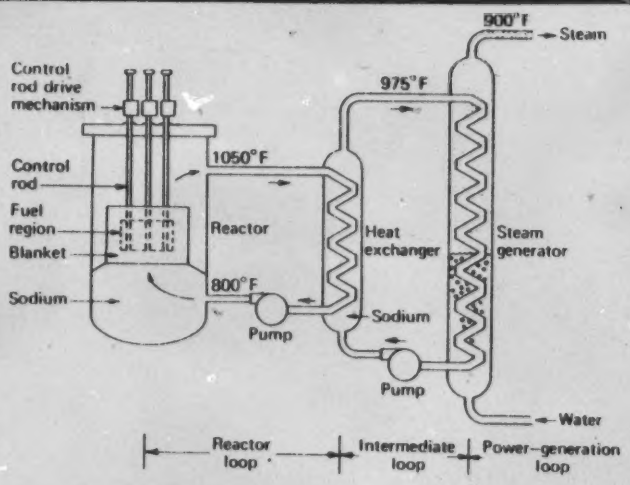
A neutron strikes a uranium 238 nucleus (called a "fertile" nucleus) and changes it into uranium 239 which then changes, through a sequence of spontaneous nuclear reactions, into plutonium 239, a long-lived material which can serve as a fuel in a reactor.

This process takes place, of course, in conventional reactors. What is important is the ratio of fissioned nuclei to the fertile nuclei converted to fuel. In conventional reactors this "conversion ratio" is 0.4 or 0.5 which means that 1 fertile nucleus is converted for every 2 fissionable nuclei destroyed. In the breeder reactors this ratio is expected to be 1.1 to 1.3. Thus, in the optimistic case, about 4 fissionable nuclei are formed for every 3 destroyed.

A relevant measure of the merit of a breeder is the "doubling time," the time needed for it, not only to reproduce fuel for its own use, but also to produce enough to fuel another similiar reactor. In the first experimental breeders this may be as high as 50 years; advanced breeders have been projected to have doubling times as short as 10 to 15 years - conveniently the recent doubling time of electrical energy consumption. Thus breeder reactors can perhaps be "tuned" so that fuel and power production matches electrical energy demand.

The increased conversion ratio is bought at some price. To convert uranium 238 to plutonium 239, "fast" or high energy neutrons are needed and so the conventional water moderator and cooling fluid cannot be used. It is planned instead to use molton sodium or perhaps helium. A schematic diagram of the breeder reactor is shown below.
The fuel assembly and control rods are similar to those in a conventional reactor. Around the fuel region, however, is a "blanket" of uranium 238 assemblies in which the plutonium is formed.

Molten sodium circulates through the core, cooling it and carrying the heat energy away. Since sodium becomes radioactive under the intense neutron bombardment inside the reactor, it must not be allowed to contaminate the rest of the system. A second cooling loop, also sodium, picks up the heat from the first loop and is used to heat the steam.



By using sodium, steam temperatures as high as 1050° F can be reached and so the conversion of this heat energy to mechanical energy at the steam turbine (and then to electrical energy at the generator) can proceed at fairly high efficiency. The expected efficiency of 40 percent for the breeder reactor will approximate that of the best modern coal-fired plants.

Sodium, however, is a very active metal (it burns in contact with air or water, for instance). It offers both advantages and disadvantages as a coolant. It will have to be kept in liquid form and will require development of appropriate pipes, valves, pumps, etc. Since it has a high boiling point, however, it will be used at low pressures rather than at the high pressures needed for steam. This will make for simplicity and safety.

There are technological problems awaiting solution, but there is already much experience from small experimental breeders in this country and from breeder programs in other countries. The more difficult problems are not technological, but are those of resource availability which we have discussed and the economic and social problems which we will discuss next.

ECONOMICS

One set of arguments for and against the breeder reactor turns on economic issues. Proponents attribute huge savings to its introduction - from $20 to $50 billion between 1970 and 2020 according to a recent ERDA study. Critics see no savings and predict increased costs. The resolution of this disagreement depends on such factors as the cost of uranium (which will depend on resource availability and total electrical demand as we have already discussed) and on the capital costs of the breeder.

The major economic advantage of the breeder is its relative insensitivity to the cost of

uranium. As an example, a $10 per pound rise in the price of U_3O_8 increases the cost of electricity from a conventional reactor about 0.5 mills per kw-hr (or about 0.05 cents out of 3 or 4 cents per kw-hr). The same price rise would increase breeder-produced electricity 0.015 mills or 0.0015 cents. If, therefore, one anticipates a long-range price squeeze on uranium, then the breeder can save significant amounts of money.

Most of the cost of the breeder is in its construction and, in particular, in the interest paid on the capital investment. Maintenance and fuel costs make up a small percentage of the total. The amount of capital needed for a breeder program is staggering, $150 billion before the year 2000 in a General Accounting Office (GAO) estimate. (The Federal R & D share of this is about $14 billion.) The demonstration LMFBR which was planned for Clinch River, Tennessee was expected to cost more than $2 billion (for a 380 Mw plant). The GAO estimate is for a cost of $1 to $1.2 billion - in 1974 dollars - for each 1,000 Mw breeder placed in operation.

The costs for other types of electrical generation will be high also. The conventional reactors cost about $1 billion per 1000 Mw and coal fired plants about $800 million. It is the expectation of the breeder proponents, of course, that as the price of coal, oil, and uranium increases, utilities will be willing to invest more in a plant in return for low 30 to 40 year fuel costs.

The estimates which attribute high dollar savings to the introduction of the breeder make the following assumption. Electrical demand will grow (until at least the year 2000) at about 5.2 percent per year (compared with 7% growth rate in 1960-1970) and by the year 2000, about two-thirds of the primary energy will be used to generate electricity and half of this generation will be nuclear. The cost of uranium will rise steadily. The cost of breeder reactors will drop as more is learned about them and construction and fabrication practices become standardized.

Breeder critics have performed their own cost benefit analyses with contrasting results. In "Bypassing the Breeder - A Report on Misplaced Federal Energy Priorities" (see bibliography) it is concluded that by 2020 the cost of the R & D for the breeder program will be 10 times the savings. The assumptions in support of this are that: the "potential" resources (see the previous table) will, in fact, be found and developed; electricity demand will slacken (as in fact it did during the recession years of 1974 and 1975) as the price of electricity continues to rise and more conservation efforts begin to bear fruit; and that the breeder costs will not decrease along some "learning curve," but will stay constant or increase. They support this last argument by the experience with present-day reactors; capital costs of the conventional reactor increased from about $200/kw to $1000/kw in less than a decade and only about half this increase can be attributed to inflation.

There is a related worry over the immense amount of capital which will be needed for the breeder program. The energy industry is the most capital intensive of all the industries. (This means that to a large extent it employs dollars rather than people.) The electric utilities are the most capital intensive of the energy industries and the breeder will follow this pattern. (So, in all likelihood, will fusion, solar energy farms or solar satellites). It is argued, therefore, that the dollars invested in the breeder will not only deprive other energy options of that R & D money, but will generate much less employment than they would if invested in less centralized energy options (conservation practices, solar home heating, etc.) or in non-energy related activities.

There is clearly no common ground of agreement on breeder reactor economics - a difficult situation for a Fact Sheet to deal with. The reader will, therefore, have to make her/his own assessment of the weight to be given to the different assumptions and projections. In arriving at a final cost/benefit ratio, however, the environmental and social costs, dealt with in the next two sections, will also have to be considered.

ENVIRONMENTAL EFFECTS

The breeder offers environmental advantages which go beyond the nuclear vs. coal advantages discussed in Fact Sheet #12. Its higher thermal efficiency leads to even smaller thermal waste. The fact that it uses uranium so efficiently means even less mining than with the conventional reactors.

The decision to enter into commercial development of the breeder will in some ways intensify the nuclear disadvantages. The breeder will represent the full maturation of the nuclear program; fission energy will be an important part of the energy mix for a few centuries and amounts of radioactive wastes, potential radioactive pollution from reprocessing plants, etc. will continue to increase.

The major concern, however, focusses on plutonium; the breeder will greatly increase the amount of that material which we will have to deal with.

LECTURE NOTES

SAFETY

Some of the environmental problems posed by the breeder reactor can be looked upon as extensions of those associated with conventional reactors. Other concerns, however, are unique to breeders.

These problems are of two types, technical and social. They are viewed, of course, quite differently from the pro and anti breeder camps. Those who oppose the breeder assert that use of the highly concentrated plutonium 239 (about 20%) instead of the 3 to 4 % of enriched uranium 235 in conventional reactors makes less certain the safety factor against nuclear explosions that the dilution of U^{235} in U^{238} provides (see Fact Sheet #12). Since there are several critical masses of plutonium in a breeder, the concern is that a meltdown might collect enough of it in one place to cause a small nuclear explosion within the plant. Core meltdowns are expected to be extremely rare accidents, of course, but if they occur they may be more serious in breeders than in conventional reactors. The breeder proponents assert that breeder fuel, in any configuration, cannot lead to a nuclear explosion.

In most critics' minds, however, the most serious problem posed by the breeder reactor is not the accident threat but the threat of deliberate misuse of plutonium. This man-made material is not only a good fuel for nuclear reactors, it is also the raw material for the nuclear bomb.

This is not a new fact. The fission reaction in the reactor and in a bomb are basically similar. In the former, it is slowed and controlled. Any material that can fuel a reactor can, in theory, be used in a bomb. In practice, however, of the three fissile elements, uranium 235, uranium 233 (which can be bred from thorium) and plutonium 239, only plutonium 239 is likely to be of use to a clandestine bomb maker because it can be chemically separated from the other fuel materials.
Thus this fuel, as it goes to the reactor and as it travels between the reprocessing plant and the fuel fabrication plant, could be the target of a hijacking operation. Likewise, without proper safeguards, a breeder reactor or plutonium containing fuel sold to another country could be the equivalent of an invitation into the nuclear club. The refinement of the raw material is the only really difficult step in the fabrication of a nuclear weapon. India created its bomb out of plutonium reprocessed from research reactor fuel and several undergraduates science students in this country have designed nuclear bombs that were judged as probably workable by weapons experts. (Other experts have suggested that the students would probably have been killed in the process of making the bombs.)

"The Plutonium Economy," as this anticipated new nuclear age is being called, will present problems which are qualitatively and quantitatively different from any we now face. The qualitative problems derive from the need for much greater security over the vulnerable parts of the nuclear fuel cycle than we now exercise. The quantitative problems have to do with the amount of plutonium. Plutonium is presently formed in special reactors and separated out for weapons use as a part of our defense program. In the fuel from power plants, since there is no commercial reprocessing plant currently in operation, the plutonium remains in the stored spent fuel, amply protected from misuse (except with great difficulty) by the radioactive fission products mixed in with it.

There will be an increase in plutonium in transit and in storage if we begin to recycle it as planned. Significant quantities of plutonium - about 200 Kg per year per 1000 Mw - are bred from U^{238} in present reactors. Thus the 42,000 Mw of nuclear generation now in operation produces 4 to 5 tons per year. The breeder yields about the same net plutonium production, but maintains about 5 times as much in the fuel cycle than do conventional reactors. With the breeder program in full bloom, however, the output of plutonium (net production plus recycled fuel) will be measured in thousands of tons. An AEC* projection for the year 2020, with half the reactors breeders, was for 30,000 tons of plutonium to be produced per year. It takes only 4 to 10 kilograms (13 to 22 lbs.) of plutonium to make a nuclear bomb, so scarcity will not be the problem.

The potential danger of plutonium proliferation is yet to be solved. Stepped up security and concentration of reactors and processing plants in a single easily guarded area is one proposal. A more imaginative one is to forego the uranium 238 to plutonium 239 breeding reaction entirely and use instead thorium 232 as the fertile element and convert it in a breeder to uranium 233. Thorium is at least as abundant as uranium. The uranium 233, if carefully controlled and guarded (it is a potential bomb material also), could be blended with U^{238} and thus frustrate would-be bomb makers. Whatever the solution, an agreed to and workable international plan to protect the plutonium from criminal individuals or irresponsible nations must be established before we enter into a large-scale breeder program.

* This agency no longer exists. It was abolished when ERDA was formed in 1975.

LECTURE NOTES

SUMMARY

The breeder program offers the promise of hundreds of years of energy from existing supplies of uranium. If the program comes into being as originally designed, this type of reactor will not only produce an increasingly important fraction of the electric power in the next century, but will provide the fuel for conventional reactors which will also generate electricity.

The breeder reactor program has met with much opposition. Arguments are made that it will not be needed - that the potential uranium supply is large enough to provide for the smaller electrical demand which conservation and higher prices make realistic and that solar or fusion power can then take over. It is objected to on economic grounds as well. It will be one of the most capital intensive facilities in the already capital intensive energy production industry, and this capital will thus be denied to other areas. There are also unresolved safety issues raised: questions of local safety against reactor accidents and of national and international safety from diversions of the plutonium fuel to bomb making.

The future of the U.S. breeder reactor program is at present in doubt. The President's Energy Message of April 20, 1977 called for a reduction in the breeder program, and an indefinite postponement of the plutonium reprocessing program. The plan to build the Clinch River demonstration plant was also postponed indefinitely.

It may be possible, in fact, for the U.S. to obtain the energy it needs without resorting to the breeder. This country has several other energy sources - coal is the most important one - available to it. Other countries, Japan, France, and England, for instance, with less energy flexibility may see the breeder not as an option, but as a necessity.

The breeder, however, has been postponed, not abandoned, and an increasing demand for electricity, combined with a uranium shortage and/or problems with coal, may bring us back to a decision point on the breeder in the next decade. This decision is not one that the U.S. can completely control. It is, however, one that will strongly impact the entire energy, environmental, economic, and social fabric of this country and the world. It is a matter of crucial public concern and responsibility.

REFERENCES

1. "The Breeder Reactor," U.S. Atomic Energy Commission (Washington: AEC) 1973 (Available from: USERDA, Technical Information Center, Oak Ridge, Tennessee 37830).

2. "Review of National Breeder Reactor Program," Report by the Ad Hoc Committee to Review the Liquid Metal Fast Breeder Reactor Program of the Joint Committee on Atomic Energy, Congress of the U.S. (Washington, USGPO) January 1976.

3. "Issue for Consideration - Review of National Breeder Reactor Program," Materials compiled by the Staff of the Ad Hoc Subcommittee to Review the Liquid Metal Fast Breeder Reactor Program of the Joint Committee on Atomic Energy, Congress of the U.S., 94th Congress, 182 Session (Washington: USGPO) August 1975.

4. "Poor Buy: The Liquid Metal Fast Breeder Reactor," T.B. Cochran, Environment, 17, 12-20, June 1975.

5. "Plutonium Recycle: The Fateful Step," J.G. Speth, Thomas Cochran, Arthur Tamplin, Bulletin of the Atomic Scientists, 30, #9, September 1974.

6. The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique, Thomas B. Cochran (Baltimore, Md: Johns Hopkins Press) 1974.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

FACTSHEET

United States Department of Energy
Assistant Secretary for Intergovernmental and Institutional Relations
Education Programs Division

14. NUCLEAR FUSION

John M. Fowler

INTRODUCTION

Most of the energy we use on this planet is converted from its stored (potential) form by the combustion reaction - by "burning" fuels. The important feature of this combustion reaction is that it is, in scientific language, "exothermic." It releases more energy than is required to start or keep it going.

In the search for ways to replace the primary energy of fossil fuels, we have turned to different kinds of "exothermic reactions, nuclear ones. Fission, which is the energy source for nuclear power plants, is one such reaction. In this Fact Sheet we describe another, the fusion reaction, one of the most promising exothermic reactions - from the point of view of energy released per pound of fuel - that science has yet discovered.

It is not enough, however, for a reaction to be exothermic. To be a large scale source of energy, a reaction must be self-sustaining or, to use fission terminology, something like a "chain reaction" must occur. It must be arranged so that some of the energy released in each event is absorbed by the surrounding fuel material causing further reactions to occur. Only under this condition do we get more energy out than we put in. We light a fire, for instance, supplying energy with a match, and unless we have arranged our fire so that small sticks catch fire and heat larger sticks to their kindling point, the fire does not burn. It is toward the achievement of this second condition that fusion scientists are currently struggling.

The fusion reaction was first scientifically demonstrated and studied 45 or so years ago. It has glimmered brightly before us for almost 30 years, giving hope for a return to the Eden of abundant energy. But to date, the only man-made, self-sustaining fusion reaction has been the explosion of a "hydrogen bomb" - and that has nothing to do with Eden.

Fusion uses "fuels" which are essentially inexhaustible. It appears to be relatively benign environmentally and safe. It does not (unless it is designed to do so) produce materials which can be sidetracked for bomb making. Only solar energy, in fact, can compete with its promise. But the achievement of this promise, on a commercial scale, is surely the most difficult technical task that our species has yet undertaken. We describe this task and the progress towards its accomplishment in the sections which follow.

RESOURCES

The resources for the fusion reactions are deuterium, an isotope* of

---

* Isotopes of elements differ only in the number of uncharged neutrons in the nucleus. They are chemically identical. See Glossary, Fact Sheet #18.

This material was produced by the National Science Teachers Association under contract with the U.S. Energy Research and Development Administration. The facts, statistics, projections, and conclusions are those of the authors.

hydrogen, and the light metal lithium. Lithium is an indirect resource since the other important fusion fuel, tritium, a radioactive isotope of hydrogen, will be "bred" from it in the fusion reactor.

Deuterium is rare. It combines with oxygen to make the laboratory curiosity "heavy water." In a natural sample of water, only one molecule in 6500 is of that variety. In other words, in 60,000 pounds of water, there is only about 1 pound of deuterium. But water is enormously abundant and the Earth's oceans, rivers, and lakes contain ten trillion tons of deuterium. The world's total "recoverable" resources of coal are estimated to be only 6 to 8 trillion tons. In a fusion reaction between deuterium nuclei, the total amount of energy released is 340 million Btu per gram of deuterium or about 1.5 quadrillion (1.5×10^{15}) Btu per ton. In contrast, coal releases at most 25 million (25×10^{6}) Btu per ton when burned. Thus each ton of deuterium could produce 60 million times more energy than a ton of coal.

The energy content of all this deuterium is difficult to comprehend. The total energy the world uses in one year could be obtained from 200 tons of it. Even if the world consumed twice the annual amount of energy it now does, the deuterium supply would last about 50 billion years - which is longer than we can be sure the world will last. The use of deuterium as a fuel is the most attractive fusion possibility.

The easier reaction to achieve experimentally, and therefore, the one presently emphasized, uses the even rarer isotope of hydrogen, tritium. Lithium, from which tritium could be made, is less abundant than deuterium, but from its known reserves alone (and there has been little exploration for lithium) we could fuel the world at twice its present level for almost 50,000 years.

It will require energy, of course, to separate that one deuterium atom from its 6500 or so chemically identical brothers (or is it sisters?). We do that now; heavy water is produced routinely, with the energy cost of providing a gram of deuterium substantially less than 1 per cent of the fusion energy available from that gram. Clearly, fusion energy will not be limited by fuel resources. Limits may be set, as we shall see, by other resources - capital, for instance, or the materials needed to build the complicated plant and its machinery.

TECHNOLOGY

The fuel picture for fusion has a rosey hue. We can give almost the same tint to the evaluation of environmental effects. In the discussion of technology, however, a different color - the gray haze of uncertainty, shall we say - intrudes. In spite of more than 2 decades of determined effort by scientists and engineers of several countries, the demonstration of a controlled, self-sustaining fusion reaction has not been achieved and beyond that achievement lie many known and many more unknown technical challenges.

Fusion is a nuclear reaction. It is, in a sense, the opposite of fission. The release of energy in fission occurs because a large nucleus (uranium, for instance) is split into two smaller ones. In the fusion reaction two very small nuclei combine to form a larger one. In both cases, the mass of the end product(s) is less than the mass of the original reacting nuclei and this lost mass is converted into energy.

The four fusion reactions which are the most interesting as future energy sources are the two reactions between deuterium particles, (D in the equation below):

1. $D + D \longrightarrow T + p + 3.3$ Mev (75 M Btu/gm)
2. $D + D \longrightarrow {}^{3}He + n + 4.0$ Mev (92 M Btu/gm)

and the two reactions of deuterium with the products of those reactions, (T) tritium and ^{3}He (helium e, a rare isotope of helium).

3. $D + T \quad {}^{4}He + n + 17.6$ Mev (313 M Btu/gm)
4. $D + {}^{3}He \quad {}^{4}He + p + 18.3$ Mev (334 M Btu/gm)

The promising resource picture that we have already anticipated is contained in these four nuclear equations. The energy released is given both in the units of nuclear physics (Mev - defined in the Glossary, Fact Sheet #18) and in millions of Btu's per gram. The hope for low environmental impact is also contained in them. Of all the participating reaction components, deuterium (D), tritium (T), helium 3 (^{3}He), the proton (p) and neutron (n) and finally, common helium (^{4}He), only tritium is radioactive. It is short lived (with a half-life of 12 years) and its biological - radiological hazard is, at least thousands of times less than that of the fission products.

These equations also suggest difficulties to the experienced eye. The reaction products, in particular, the neutrons (n) and protons (p) which carry away most of the energy can create radioactivity in the materials they strike. This "experienced eye" will also note that the particles, D, T, or ^{3}He which must react, which must get close enough together to each other to allow the short range nuclear force to take over, are electrically charged. They will repell one another. Our "experienced eye" will ask "How do you bring them together?"

LECTURE NOTES

The problem is fairly simple to state. The reacting particles must be given enough energy that they will collide in spite of the electrical force trying to shove them apart. In a simple analogy, they must roll up over a hill before they crash down together into the deep valley and give up energy.

The early study of fusion reactions was accomplished with "particle accelerators" - cyclotrons, Van De Graff generators, etc. In these experiments a deuterium particle was hurled against a stationary target of deuterium or tritium. Created in this fashion, however, the reactions are not self-sustaining. Even though net energy is released in each successful reaction, most of the incoming particles miss and the emerging particles do not hit others and cause a chain reaction. Much more energy is used overall to cause reactions in these experiments than is released by them.

There are, however, other examples to guide us. Fusion reactions do occur in the sun and in hydrogen bombs. In those cases, energy is supplied in the form of heat. If a mixture of deuterium and tritium (D and T) can be held together and brought to a temperature of 50 to 100 million degrees Celsius (C), the fusion reaction will take place. The ignition temperature - as this reacting temperature is called - is about 500 million °C for a D + D mixture. Since the ignition temperature for D + T mixtures is lower, the experiments now underway, concentrate on this reaction (reaction 3 of the above list).

The enormous temperatures which are needed greatly limit confinement techniques. Ordinary vessels - bottles, cans, and tanks - cannot be used. The reacting particles must be suspended in a vacuum, free of any matter which could conduct their heat away. We know of two ways to accomplish this, magnetic confinement and inertial confinement.

In magnetic confinement, the deuterium-tritium mixture is given enough energy so that the electrons are stripped from the nuclei, forming a "plasma" of charged electrons and nuclei. This plasma can be controlled by a magnetic field much in the same way that a beam of electrons is controlled in a television tube. Several different experimental approaches using magnetic confinement are described below.

In inertial confinement, a solid target (a droplet or sphere) of deuterium and tritium is heated extremely rapidly so that it reaches the ignition temperature for fusion before it can expand and reduce its density. Bombardment of a small sphere of deuterium from all sides with a high powered laser is one method which may achieve this.

Magnetic Confinement: There are three basic magnetic confinement systems under development.

1. Toroidial-shaped chambers ("doughnuts"), in which the plasma travels around inside an evacuated chamber: The Russian-invented Tokamak is the most successful of these and about 70 percent of the U.S. effort is going into similar devices; examples are the PLT (Princeton Large Torus), ORMAC (Oak Ridge Tokamak), Alcator at MIT, Doublet IIA at the General Atomic Company in LaJolla, California, and the much larger TFTR (Tokamak Fusion Test Reactor) under construction at Princeton University.

2. Magnetic mirrors: These are linear tubes in which the magnetic field which confines the plasma is so shaped that it turns the particles around at each end, as a mirror does light beams. The most successful of these devices is the 2X-IIB at the Lawrence Livermore Laboratory of the University of California. Mirrors are now the principle alternative to Tokamaks.

3. The magnetic pinch device: In these the interior space is filled with plasma and then the plasma is "pinched" by a rapid compression of the magnetic field. This is accomplished by increasing the strength of the field and forcing the plasma toward the center of the tube. The Scyllac at Los Alamos is an example of a pinch device.

Heating: In addition to the proper confinement conditions, the plasma must be heated to 50-100 million °C. Heating can be accomplished in three ways.

1. The plasma may be heated by induced electric currents. The plasma heats up like a resistive wire does when current flows through it. The toroidial machines rely, in part, on this type of heating.

2. A plasma can be heated by injecting an energetic beam of nuclear particles into it. Techniques of firing beams of uncharged deuterium atoms into the plasma are used in the toroidial and the mirror machines.

3. The plasma acts in some respects like a gas (a gas of charged particles). Therefore, like a gas, it can be heated by compression. The magnetic pinch devices not only confine their plasmas, but heat them.

Inertial Confinement

The confinement problems can also be solved by freezing the mixture of deuterium and tritium to form a solid. The major problem left is that of heating and compressing the solid to the temperature and density needed for the reaction to occur.

Experiments with inertial confinement have proceeded along the following lines. A small frozen droplet of the fusion fuel, preferably spherical in shape and of very small diameter

(less than a millimeter) is placed in the center of an evacuated chamber and bombarded from all sides by an energy source - a laser, or a beam of charged particles (ions or electrons).

Lasers are powerful sources of light that can be accurately focused to a very small spot. In order to bombard the pellet symmetrically, from all sides, the main beam is usually broken up into several smaller beams by a system of mirrors and these beams are then all brought to bear on the target sphere. The burst of energy must be very short, lasting only about 10^{-9} seconds in order that the deuterium-tritium mixture is heated rapidly, without expanding. As the energy hits the outside layer the material essentially vaporizes and in rushing outward exerts a reaction force back against the sphere (this is the principle of a rocket) which "implodes" the sphere, crushing it inward and greatly increasing its density. The high temperature and high density allow ignition of the fusion reaction and the pellet explodes. Most of the energy is carried out by neutrons released in the fusion reaction.

Nuclear Fusion in Practice

For self-sustaining fusion to occur, the plasma density, confinement time, and temperature must all be above certain values. Satisfactory values of each of these parameters have already been achieved separately, but not in the same machine at the same time.

That requirements for density and confinement time are related can be seen from the following simple argument. What we are seeking is a chain reaction, of sorts, in which the energy released by one fusion event causes another one. To occur, either the particles must be very close together (have a high density) or there must be sufficient time for the energetic particles to wander around until they hit other ones (a large confinement time).

The "yardstick" for fusion reactor performances is the so-called "Lawson criterion" which says, that for a self-sustaining, energy producing D + T fusion reaction to be possible, the product of the particle density and the confinement time must be about 10^{14}. In the best performance of a Tokamak-type machine, so far, that of MIT's Alcator, a product of density and confinement of 2×10^{13} (a factor of about 5 below that breakeven point) was reached. A magnetic pinch machine (the Scyllac) recorded a product of 2×10^{12}, while the best that a mirror machine has done so far (the 2X-II) is 10^{11}.

The record on ignition temperature has also improved. The Tokamak devices are still operating at factors of 5 to 10 below ignition. The PLT and the Soviet Tokamak (T-10) have produced temperatures of 20 million °C and 10 million °C respectively. The 2X-II mirror machine has produced a record temperature of 230 million °C, getting closer to a demonstration of energy breakeven and ignition.

Laser fusion in practice: The principal problem for laser fusion is to heat the fuel pellet efficiently and evenly so that it will be compressed symmetrically. The best achievement to date has been a temperature of 90 million °C at a density-confinement time number of 10^{12}. Some fusion-produced neutrons were observed. Further improvement is occurring as the construction of new, more powerful lasers is completed. There are still many problems to be solved, however, before this technique can be called a success.

Fusion Reactors

Given the current status of fusion and the scientific and engineering problems which must be solved before the "scientific feasibility" of fusion can be demonstrated, it may seem premature to spend time considering what a commercial power producing plant would look like. It is important, however, to anticipate some of the problems which will remain after the scientific success is achieved. There are a few general points worth making.

The magnetic confinement machines will all be large, it appears, with generating capacities in the thousands of megawatts range. The major components will be the chamber itself and a surrounding thick blanket of lithium - probably in a molton form-which will absorb the neutrons and convert their energy to heat. The lithium will also be the source of the tritium and ^3He which will be created by reactions between the neutrons and the lithium nuclei and then separated from the blanket and used as fuel. Heat extracted from the hot lithium will be used to create steam to turn a steam turbine. It is expected that high temperatures will be achieved and that efficiencies will approach 40 percent.

There is some hope for even greater efficiencies. In fusion reaction 4 (above list), the end products are charged. It may be possible to collect these particles, and the electrons accompanying them, separately, and directly convert some of the kinetic energy into electrical energy. Efficiencies in the 80 percent range may be feasible.

Unless some unforeseen breakthrough is accomplished, however, the first fusion reactors will be huge machines, practical only as sources of large amounts of electrical energy. They could also be used for chemical processing or to breed fissionable fuel. They will

certainly increase the already important centralization of energy production.

Laser fusion may depart from this trend. The energy released in each explosion will be relatively small. They will be pulsed, one small explosion following another. It may be that generators with capacities as low as 100 Mw will be feasible.

A laser fusion generator will be quite different than the magnetic machines. The reactor vessel will be a fairly large sphere strong enough to withstand the repeated small explosions as the pellets are bombarded. Lithium will be introduced in some manner around the inside surface of this vessel. It will perform the same function as in the magnetic devices, creating new fuel, absorbing the energy from the neutrons, and converting it to heat. Ample challenge still remains, for example, in the search for means to make inexpensive little target pellets (the electricity generated from each explosion is worth only a few cents) and in constructing a vessel that is not weakened by the neutron bombardment and/or damaged by the explosions.

Environmental Effects, Safety, Etc.

We have described the major advantages of fusion reactors in the section on Resources. They also seem to offer significant advantages over fission reactors in their possible effects on the environment and on the society which uses them.

The threat of an accident is greatly reduced. Fusion reactors will not contain the huge amounts of radioactive material characteristic of fission reactors. Tritium will be produced, but the entire system will be designed to recapture and consume this material and its stockpile, even if released, presents much less of a threat than the fission products. Radioactivity will be produced in the reactor materials by the neutrons and, while this may be a problem, it probably can be reduced by proper choice of construction materials.

Also, importantly, there is no "critical mass" involved in fusion. Any malfunction would destroy the plasma and stop the reaction. Although there will be some "after heat" remaining in the reactor structure, it will be much less than that in a hot fission reactor core and it will not pose the melt-down problem.

The radioactive waste problem would be ameliorated. Some storage of discarded materials may be necessary, but the long term, large volume storage problem facing us in a fission future would be avoided.

Perhaps the greatest relief that successful fusion power generation could offer us would be from the plutonium nuclear bomb threat. Unless neutrons from fusion reactions were deliberately used to breed plutonium from uranium 238 (as has been proposed), no potential bomb making materials would be produced, transported, etc., a very significant advantage.

The production of fusion fuels, because of the enormous amounts of energy they contain, should cause little disruption of the environment. Removing one hydrogen atom in 6500 from the ocean will have no measurable effect on it and the amount of lithium needed is equally miniscule when compared to projected needs of coal or even uranium.

The fusion reaction would be, it appears, as environmentally benign as any technology except solar energy.

SUMMARY

The fusion reaction, relying on abundant deuterium for fuel, could provide humankind with energy for millions, perhaps billions, of years and at modest cost to the environment. Unfortunately, in spite of almost 30 years of scientific and engineering labor, and a billion or so dollars spent in the U.S., we have not yet produced a self-sustaining, controlled reaction.

The present challenge of fusion is to confine the D-T mixture at sufficient density, hold it together long enough, and get it hot enough to cause the reaction to occur. This accomplishment will demonstrate the "scientific feasibility" of a self-sustaining fusion reaction. Even after this is achieved, however, a host of problems will remain. A very complicated piece of machinery will have been constructed: large vacuum chambers, huge magnets (which may be "superconducting" magnets cooled by liquid helium) and tanks and pipes of extremely hot lithium. There will not only be enormous differences in temperature to sustain, but all of this equipment will be bombarded by an enormous flux of neutrons which will not only create radioactivity but may weaken the metallic structures. These engineering challenges may be as great as the scientific ones. Beyond them remain the economic challenges. Can all this be constructed cheaply enough and operated long enough before breakdown to produce electricity at a competitive price?

As we have said, laser fusion is particularly questionable economically. Lasers themselves are inefficient, converting only about one percent of the input of electrical energy into an output of light. More efficient lasers and very inexpensive target fabrication techniques are among the developments which are necessary to make laser fusion a competitive source of electricity.

A timetable for this "uncertain certainty," as it has been called, is thus not very reliable. The one put forward by ERDA anticipates the production of ignition temperatures in plasmas in the 1978-1980 period, releases of thermal energy from fusion in the new Tokamak facility of 1982, production of electrical power by the late 1980's, and the operation of a commercial scale demonstration reactor by the late 1990's. Fusion can not contribute importantly to our energy supplies until the next century.

ERDA support for fusion (and the previous support from the former AEC) reached the $30 million level at about 1960 and remained at about that level for the next decade. It had grown to about $180 million by 1975 and is estimated to be $390 million in 1977.

It does appear that the support and manpower committments to the program are finally approaching a level that augers well for success. Success, however, is never guaranteed and, even after the achievement of a scientific demonstration of feasibility, there will remain a staggering number of engineering problems to be solved.

The environmental problems and social hazards which accompany fission also seem of less concern than with fusion. It will, however, continue one trend which itself may pose a social problem - the increasing size, complexity, and centralization of our energy production industry. There are questions that need to be asked in this area - but there is time to ask them.

The entire fusion research effort is different from any we have yet undertaken, not only because of the difficulties we have emphasized, but also because of its long range nature. It is an energy source, which if it succeeds, is not for this generation, but for those which follow. It could be a much appreciated inheritance.

BIBLIOGRAPHY

1. Controlled Nuclear Fusion, Glasstone, ERDA, Technical Information Center, Oak Ridge, Tennessee 37830.

2. "Fusion Reactors as Future Energy Sources," R.F. Post and F.L. Ribe, Science 186, 397-407, November 1, 1974.

3. "The Prospects of Fusion Power," William C. Gough and Bernard J. Eastlund, Scientific American 224, 2-16, February 1971.

4. "Nuclear Fusion," R.F. Post in Annual Review of Energy, Vol. 1, Jack M. Hollander, editor (Palo Alto, California: Annual Reviews, Inc.) 1976.

5. "Fusion Power By Laser Implosion," J.L. Emmett, John Nuckolls, Lowell Wood, Scientific American 230, 24-37, June 1974.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from: ERDA-Technical Information Center P.O. Box 62, Oak Ridge, TN 37830

LECTURE NOTES

CURRICULUM GUIDE OUTLINE:

3.60 THERMAL
- 3.61 GEOTHERMAL
- 3.62 SOLAR
- 3.63 CRYOGENIC (SUPERCOLD)

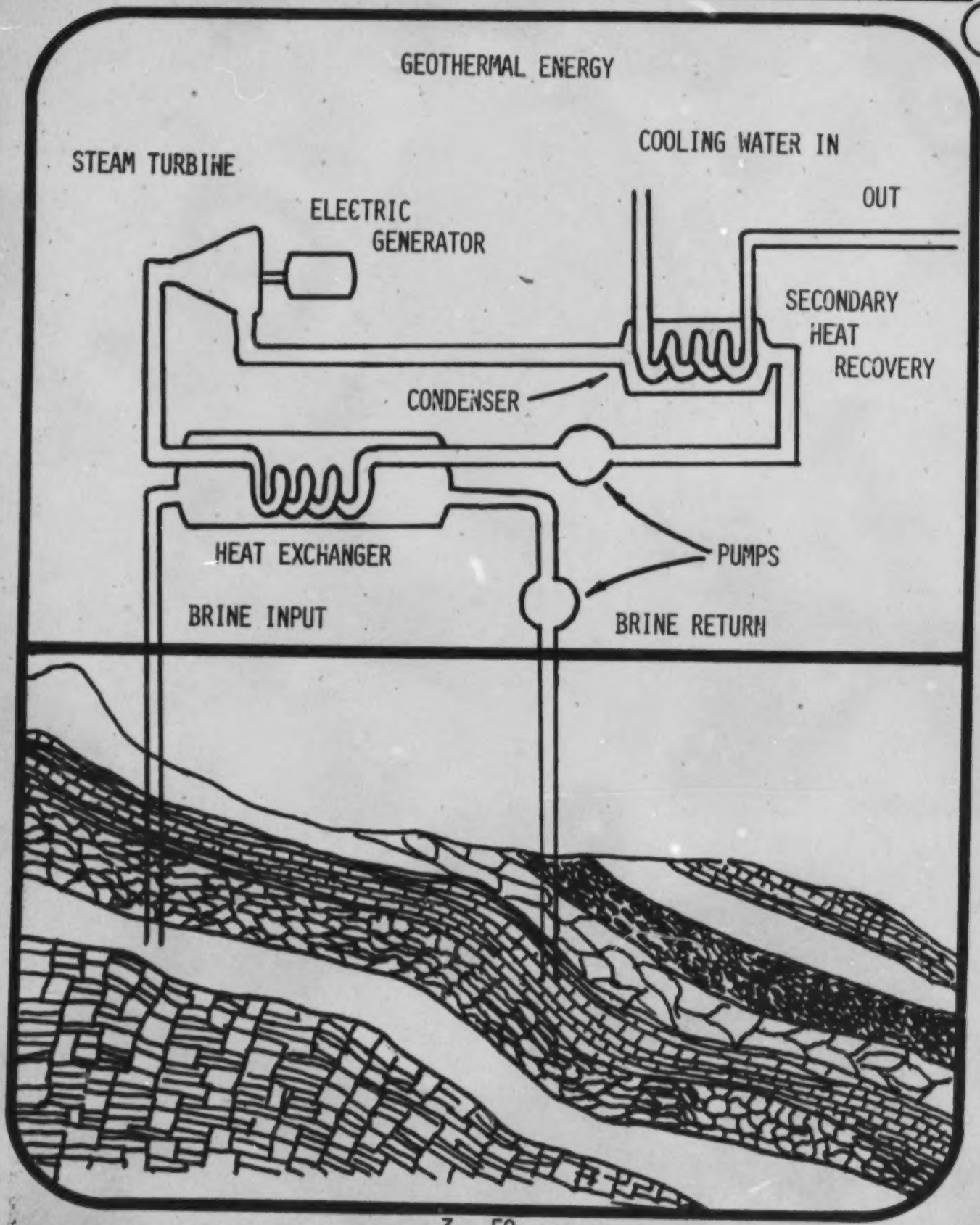
FOR A DISCUSSION OF GEOTHERMAL ENERGY, REFER TO FACT SHEET #8, AND VISUAL #8. FOR A DISCUSSION OF SOLAR THERMAL ENERGY REFER TO FACT SHEETS #5 AND #7. CRYOGENIC (SUPERCOLD) IS A FORM OF ENERGY EVEN THOUGH WE TEND TO THINK OF HEAT AS ENERGY AND COLD AS A LACK OF ENERGY, WHICH IS A NOTION THAT IS PRECISELY CORRECT. HOWEVER, WORK IS DONE BY AIR RUSHING INTO AN EVACUATED TANK JUST THE SAME AS WORK IS DONE BY AIR RUSHING OUT OF A COMPRESSED AIR TANK. IN THE SAME MANNER, WORK IS DONE BY HEAT RUSHING TOWARD A COLD AREA JUST AS IT IS "COLD TOWARD HOT".

SUGGESTED ACTIVITIES: MANY OF THE ACTIVITIES SUGGESTED IN UNIT FOUR ARE ALSO APPRIATE HERE. IN ADDITION THERE ARE MANY ACTIVITIES SHOWN IN DETAIL IN "SCIENCE ACTIVITIES IN ENERGY" SERIES. THE SERIES INCLUDES:

1. CONSERVATION
2. WIND ENERGY
3. CHEMICAL ENERGY
4. ELECTRICAL ENERGY
5. SOLAR ENERGY
6. SOLAR ENERGY II

SOURCES ARE LISTED IN APPENDIX.

VISUAL # 8


GEOTHERMAL ENERGY
STEAM TURBINE
ELECTRIC GENERATOR
COOLING WATER IN
OUT
SECONDARY HEAT RECOVERY
CONDENSER
HEAT EXCHANGER
PUMPS
BRINE INPUT
BRINE RETURN

FACTSHEET

National Science Teachers Association

8. GEOTHERMAL ENERGY

John M. and Kathryn Mervine Fowler

INTRODUCTION

Geothermal energy, the natural heat of the Earth, promises to be an important source of supplemental power in selected areas around the world. It is estimated that the Earth's geothermal heat may represent a total energy resource equal to 21 million tons of oil per square kilometer of the Earth's surface. While most of this energy is too diffuse to be recovered, there are concentrated pockets of heat within the Earth's crust that are accessible and that could provide a significant contribution to local energy needs. Currently, two geothermal fields account for two-thirds of the world's total geothermal generating capacity: the 500 Mw* capacity field in California, The Geysers, and a comparable site at Larderello, Italy. Increased exploration and new technologies could increase the total U.S. geothermal generating capacity as much as 20,000 Mw by 1985. This would represent about 2 percent of the total electrical generating capacity expected by then.

RESOURCES

Geothermal energy is primarily the product of a few elements in the Earth's core which release energy as they radioactively decay. This energy is then converted to heat energy that keeps the core molten. In certain places, geological forces thrust large pools of this molten rock relatively near the Earth's crust and these form the so-called geothermal "hot spots." If the hot rocks are fissured or porous and contain water, a "geothermal well" is in the making.

At great depths, six miles or so beneath the surface, the water is subjected to tremendous pressure and is forced, as boiling water and steam, through the fissures in the Earth's crust. While some of this water and steam bursts through the surface in the form of geysers or hot springs, large deposits often remain trapped below the surface and can be tapped only by drilling wells down into the porous rock.

Estimates of the actual amount of energy available from geothermal reservoirs vary greatly; serious exploration of this vast resource began in the 20th Century. It is now estimated that U.S. geothermal reserves (i.e., the amount of energy which is both known to exist and thought to be economically recoverable using existing technology) may be sufficient to produce 60,000 Mw of electrical power, which is about 15 percent of U.S. electrical generating capacity in 1975. The ultimate U.S. resources (i.e., the total amount of geothermal energy within the U.S., including estimates for deposits which have not yet been discovered) may be 10 to 200 times that amount.

Almost all of the known U.S. resources are located within the western third of the country. California, Nevada, and Oregon have the highest concentration of known resource areas. Alaska, Idaho, Montana, New Mexico, Utah, and Washington have substantial potential. In fact, it is likely that the greatest geothermal resources will always be found in the Western region.

* See Glossary for definition (Fact Sheet #18).

This material was produced by the National Teachers Association under contract with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

LECTURE NOTES

At present our knowledge of promising geothermal sites depends on visual evidence (geysers, hot springs, volcanoes, etc.). This is a level of exploration comparable to the early oil prospecting by looking for surface oil seeps. As modern techniques are employed, estimates of the size and location of these resources will become much more precise.

Worldwide resources are even less accurately estimated, but are probably considerable. Promising "hot spots" occur in the volcanically active, earthquake-prone regions of the Earth's crust: Down the Western coast of the Americas from Alaska to Chile, down the Rift valley into Africa and across into Turkey, in the Far East along the "Circle of Fire" that borders the Pacific. Some countries have especially large resources: Two-thirds of Turkey is believed to have geothermal potential and one UN survey suggests that the geothermal potential of Ethiopia, if developed, could satisfy the present electrical needs of all of Africa. The heat is there; imagination, money, and determination are needed to bring it into service.

TECHNOLOGY

Basically, geothermal reservoirs occur in three forms: Hydrothermal, geopressured, and dry, hot rock reservoirs. Hydrothermal reservoirs, those with naturally circulating hot water or steam, are the most desirable type with present technology. Of these, the vapor dominated or "dry steam" fields--those which contain mostly steam--are the most commercially attractive, because the steam can be used as is to power turbines. The only U.S. field, The Geysers in California, is of this type. The hot water or "wet steam" fields are at a somewhat lower temperature and contain a mixture of steam and hot water. They are more difficult to work with since the steam must be clear of water for use in a turbine. These are about 20 times more common than the "dry steam" fields.

Geopressured reservoirs are perhaps the least understood type. These are usually made up of porous sands containing water or brine at high temperature or pressure. Apparently, they are formed when an overlying clay layer acts as an insulator and traps the heat flowing out from the Earth's interior. A large geopressured zone has been found along the Gulf Coast during oil and gas exploration, and it is thought to contain a very large energy potential. Energy resides in this geopressured water in three different forms. Since the water is under pressure it can drive a turbine much in the same way that water flowing over a dam does. Since it is hot, the heat energy can be used to evaporate a low boiling point gas such as freon or ammonia, and this gas can turn a turbine. Finally, there is usually a considerable amount of methane (natural gas) trapped in the water which can itself be extracted and used for fuel.

The "hot rock" systems are potentially the largest and most widely distributed resource. Of course, if you drill deeply enough--several thousand feet--there are hot rocks everywhere. However, the normal temperature gradient is about 100°F per mile, and power plants need steam temperatures of at least 400°F or 500°F. This would require wells 4 or 5 miles deep---too deep for economical operation with present techniques. There are regions, however, where such temperatures are present in rocks only a few hundred feet below the surface, such as near volcanoes. Their exploitation will require that the rock be fractured to form a reservoir area, then have water pumped into it, and the steam extracted. Such techniques remain, for now, in the realm of future possibilities.

The current technology is not very sophisticated. Drilling into dry or wet steam reservoirs is similar to drilling for oil or natural gas, except that the rock formations are frequently harder and the equipment and materials are subjected to higher temperatures and to more concentrated corrosive materials. Completed wells at The Geysers range from 200 to 900 feet and typical drilling costs range from $50,000 to $150,000 per well.

The next step in the development of technology will be directed at the "wet steam" wells. Here separation will have to take place and an exchange of heat between the water or steam and some other substance (gas or ammonia as mentioned above) arranged. If the location is fortuitous, the hot water itself may be used in space heating or industrial processes. There is some experience with these uses in the U.S. and other countries. Development of the other types wait on improvement in deep, high temperature drilling techniques, and on governmental determination to tap these resources.

GEOTHERMAL ENERGY IN PRACTICE

In the early use of geothermal sources, health rather than energy was the goal and hot springs were popular gathering places. Italy was the first country to generate electric power with natural steam by opening the Lardarello Field in 1904. This dry steam field now has 396 Mw of generating capacity. Other developed fields exist in New Zealand (where wet steam fields produce not only 170 Mw of electric power, but heat for homes and industry as well); in Japan (50 Mw); in Mexico, which has just installed a 75 Mw generator at Cerro Prieto in the north; and in Russia and Iceland.

In Iceland geothermal heat has been used for a long time in buildings; it provides almost all

of the heat for the 100,000 people in the capital, Reykjavik. Several hundred American homes and businesses are heated in this way in Klamath Falls, Oregon and Boise, Idaho.

The largest geothermal power generating complex now in operation is Pacific Gas and Electric Company's field at The Geysers, some 90 miles northeast of San Francisco. At the present time, 507 Mw of electric power are generated by 11 turbine generators (the largest has a capacity of 106 Mw). Five more power units are scheduled to be on line by 1978, raising the total capacity to 900 Mw. Beyond that, plans call for an additional 110 Mw per year, bringing the total to 1,450 Mw by 1985. (By comparison, the Four Corners coal-fired power plant in New Mexico has a capacity of 2,250 Mw).

The next new venture in this country will be in California's Imperial Valley where a $4.1 million geothermal test facility is under construction. At this facility, experience with hot water sources will be gained and the commercial feasibility of extracting minerals from the brine will be tested.

ENVIRONMENTAL EFFECTS

One of the strongest arguments for the increased exploitation of geothermal power is that there are very few environmental problems associated with it. The most serious potential problem is that boron and other chemicals (which are mixed in with the geothermal water and steam) can cause damage if they are released into nearby waters or allowed to escape into the atmosphere. It is hoped that this problem can be solved by simply re-injecting these chemicals back into the well. The other major hazard is that of land subsidence from the withdrawal of large amounts of water, but again, it is thought that this can be controlled by limiting withdrawals to a safe rate and by re-injecting water into the wells, a practice currently used in many oil drilling operations.

There is some worry that earthquakes may be triggered by re-injected water under pressure. Less significant, but still "nuisance" problems, have to do with the odor of hydrogen sulfide which is released during exploration (the familiar rotten egg smell). This can be a serious health hazard, particularly to drilling crews, if allowed to reach high concentrations. There is also considerable noise involved as steam rushes out of the well at supersonic speeds, often exceeding 100 decibels when a well is vented. Finally, large land areas are required--between 3,000 and 5,000 acres for a 1,000 Mw plant, with about 7 percent to 10 percent of this used directly for facilities, a large part of which are an unsightly jumble of pipes. However, the geothermal generating plants appear to present less environmental threat than either nuclear or fossil fuel plants, and the problems that do exist are highly localized and seem to have available solutions.

SUMMARY

Electricity generated from geothermal steam accounted for only 500 Mw of the total of 475,000 Mw of U.S. electrical generating capacity at the beginning of 1976. More significantly, perhaps, the Pacific Gas and Electric Company's complex at The Geysers produces more than one-third of San Francisco's electricity.

The potential for growth, however, is encouraging. The projections from the Project Independence Report in 1974 were for 4,000 Mw by 1985 and 59,000 Mw by 1990, under normal growth conditions, with a possibility of 10,000-50,000 Mw by 1985 and 60,000-100,000 Mw by 2000. The more optimistic predictions would amount to less than 1 percent of the total electrical generation expected by the year 2000.

It is clear, therefore, that geothermal energy cannot satisfy our overall energy needs. It can, however, be of great local importance in the West and Southwest and possibly along the Gulf Coast--if the needed technology is developed. It will no doubt make a larger contribution to home and industrial heating as new fields are located.

There will be problems. For instance, much of the geothermal potential is on Federally owned land. Who owns this steam? Should the Federal Government subsidize exploration? Should equipment, drilling rigs and generation equipment be used for geothermal production, or for its conventional uses? Finally, there are the technological difficulties already mentioned. The energy, however, is there within the Earth and we will, no doubt, tap it, more and more, as our other sources dwindle away.

LECTURE NOTES

REFERENCES

1. "Geothermal Power," Joseph Barnea, Scientific American 226: 70-77, January 1972.

2. "Geothermal Systems and Power Development," A.J. Ellis, American Scientist 63: 510-521, September/October 1975.

3. "Geothermal Energy...The Prospects Get Hotter," John F. Henahan, Popular Science 207: 96-99+, November 1974.

4. "Geothermal Energy," L.J.P. Muffler and D.E. White, The Science Teacher 39: 40-44, March 1972.

5. "Geothermal Energy," William W. Eaton (Available from: USERDA, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830) 1975.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

6. SOLAR SEA POWER
Ocean Thermal Energy Conversion

FACTSHEET

United States Department of Energy
Office of Education, Business & Labor Affairs

INTRODUCTION

The world's largest solar collector is the sea, which makes up 70 percent of the Earth's surface. Enormous quantities of solar energy are collected and stored in the world's oceans. Scientists and engineers have long been intrigued by the possibility of harnessing this source of energy for humankind.

It has been understood, since the brilliant series of explanations and demonstrations of heat engines given by the French physicist Sadi Carnot in the 1820's, that mechanical energy can be extracted from the flow of heat energy between a hot and a cooler region.

An Ocean Thermal Energy Conversion (OTEC) power plant would operate a heat engine by utilizing the energy that can be made to flow between the warm solar-heated surface water of tropical and subtropical oceans, and the deep, underlying colder water. A working fluid, such as propane or ammonia, would be vaporized by the warm surface water, the pressurized vapor would turn a turbine, and the cycle would be completed by using the cooler water to condense the gas back to a liquid.

Over the past one hundred years, several small OTEC plants have been built. The idea was first proposed by D'Arsonval in 1881, but it was another French physicist, Georges Claude, who put the idea into practice. In the 1920's and 1930's, Claude built and tested several small experimental ocean thermal power plants.

After World War II, the French government formed a state corporation, Energie des Mers, to explore the possibility of constructing an OTEC power plant off the west coast of Africa. In the United States, the idea was raised again in the 1960's by the Andersons, a father and son engineering team, who calculated that the cost of ocean thermal energy would be competitive with existing energy technologies. The Andersons' work stimulated interest in this country, and the national solar energy program began funding OTEC R&D in 1972. The Energy Research and Development Administration (ERDA) FY1977 budget requested $9.2 million for OTEC programs.

There are certain problems to be overcome before this stored solar energy can be converted for use. The best sites for OTEC plants are in tropical and subtropical seas far from the population centers where the electric power is presently needed. It is possible, however, that the electricity can be converted to energy intensive products, such as ammonia, hydrogen, and aluminum, and these products can be conveniently shipped by sea.

The early tasks of research and development will be to test the basic components of OTEC plants and study their economic and technical feasibility. Then, if all goes well, we will see the operation of a floating OTEC power plant within the next decade.

An ocean thermal energy demonstration plant could contribute 100 MW* of electrical generating capacity by 1985. It is estimated that OTEC could

* See Glossary for definition (Fact Sheet 18).

This material was produced by the National Science Teachers Association under Contract No. EX-76-C-10-3841 with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

produce 20,000 Mw or more by the year 2000. Present U.S. electrical production capacity is almost 500,000 Mw.

RESOURCES

Each year the sun bombards the Earth with about 18,000 times as much energy as man consumes. Since 70 percent of the Earth's surface is water, much of this energy goes into heating the surface waters of the tropical oceans. It also melts the ice caps which surround the North and South Poles, creating the deep cold ocean currents which flow toward the equator beneath the warm upper ocean layers. It is this temperature difference which is the potential source of OTEC energy.

A most productive area for the OTEC idea is found between the tropics of Cancer and Capricorn, where 90 percent of the Earth's surface is water and the solar radiation input is large. The ocean surface temperature in this region remains very close to 80°F all year, and the underlying flow of water away from the polar ice caps keeps the deeper water at a temperature of about 35°F. An OTEC plant would produce work from this nearly 50°F temperature difference. The amount of stored energy in this large ocean expanse is substantial. The Gulf Stream, for example, carries nearly 1,500 million cubic feet per second of near-tropical seawater through the Gulf of Florida off Florida's Atlantic Coast.

The stream flows in a path about 20 miles wide and 500 miles long. It has been estimated that OTEC units spaced a mile apart, along the length and width of the stream and operating at net efficiency of only 2 percent, could produce 26 x 10^{12} kw-hr per year--15 times the total U.S. consumption of electric power in 1975.

The resource base, as is the case with most forms of solar power, is not the limiting factor. What keeps us from tapping this large source is the need for appropriate technology. This subject will be discussed in the following section.

TECHNOLOGY

The operation of an OTEC plant offers no serious scientific challenge; its basic processes are well understood. Just as a fossil fuel plant runs on hot combustion gases, the OTEC plant runs on heat from the ocean. In both plants there is a "working fluid": The fossil fuel plant uses steam and the OTEC system uses a fluid with a lower boiling point, like propane or ammonia. In both plants the working fluid must be cooled after it has expanded and driven the turbines. The cooling is frequently provided by a nearby body of water for the fossil fuel plant, and by the deeper ocean layer for the OTEC plant.

A simple description of what might happen is the following: Ammonia would be boiled by the warm surface water, creating a gas at a pressure great enough to turn a turbine (which provides the motive power for an electric generator). The spent gas is then cooled back to a liquid in a condenser by cold water pumped from the depths, and the cycle is repeated. The efficiency of a heat engine depends on the ratio of the difference between the intake and exhaust temperature to the intake temperature (temperatures must be expressed in absolute degrees). The ideal efficiency of a heat engine operating between 80°F of the surface and 35°F of the deeper layers is only about 7 percent. Actual net efficiencies will only be about 2 or 3 percent. It is only the fact that the thermal energy is freely available that makes conversion at such low efficiency thinkable.

While no large plants of this type have yet been built, there is considerable ocean engineering experience to draw upon. Recent developments in underwater technology associated with offshore oil rigs, naval undersea activities, and deep-ocean mining will all contribute.

In preliminary design, an OTEC plant might be built on a large floating platform measuring perhaps 400 feet in diameter and extending several hundred feet down into the water. The pipe which brings the cold water from the depths would be 45 feet or more in diameter and 2,000 to 3,000 feet long.

The fact that the "boiler" will be at low pressure (150 psi vs. 1,500 psi in a steam plant) and that turbine speeds will not be very high should ease the requirements on materials and make for simple maintenance. The corrosiveness of seawater and the possibility of marine growths fouling and clogging the heat exchangers and pipes are problems to be met. The plants will have to be dynamically positioned or moored, and be strong enough to withstand storms.

One of the most significant advantages of the OTEC idea is that the solar energy is already stored in the water as heat and is continuously available. Thus, the difficulty of the intermittence of most solar conversion systems is avoided. There is a different kind of storage problem, however. The long distance between these plants and population centers will make it necessary either to transmit electric power through submerged cables or to use the electric power at the site to create pro-

ducts that can be transported by ship or barge. It has been suggested, for instance, that hydrogen could be generated by electrolysis of seawater or that ammonia (for fertilizer) could be produced using the hydrogen from water and the nitrogen from air. It may also be feasible to locate electric-intensive industries (such as aluminum manufacture) near the plants, as is currently done with some conventional power plants.

The ERDA program is concentrating on the design, construction, and testing of the components and subsystems and on the planning of storage and delivery systems. A prototype OTEC plant of about 25 Mw is expected to be built in the early 1980's for further testing. The first commercial demonstration plant is expected to be about 100 Mw in capacity (and to consist of four 25 Mw modules); the optimum commercial size may be as large as 500 Mw.

ECONOMICS

The future of the OTEC concept will be determined by the competitive costs of the electricity and other products it provides. At the present stage, it is difficult to produce convincing cost estimates. But Clarence Zener, a physicist at Carnegie-Mellon University in Pittsburgh, has provided some estimates based on further refinement of the Andersons' earlier work. At 1975 prices and using current technology, he quotes $2,100 per kw capacity, or about 50 mills per kw-hr, which is about twice the cost of nuclear and coal-fired plants.

He points out, however, several areas in which cost reductions are expected, including considerable savings in the design of the heat exchangers (the system which transfers heat from the water to the working fluid) and the condenser. The most interesting possibility for cost efficiency is to locate a large number of these plants in the tropical oceans. Conventional power plants, fossil fuel or nuclear, are built to individual specifications and cannot take advantage of mass-production techniques. Each is unique in its siting, its environmental safety problems, its power rating, etc. The location of the OTEC plants in a common environment should make it possible to mass produce their components--to build them all to one set of specifications. This would not only reduce the cost of the parts, but would reduce the overall costs even more by shortening the construction time and thus reducing the interest costs on the borrowed money. Zener estimates realistic costs of about $500 per kw in the 1980's. At this cost, one could transmit OTEC electric power 100 miles at costs competitive to those for nuclear generation of electricity.

ENVIRONMENTAL PROBLEMS

It is even more difficult to anticipate environmental problems associated with OTEC plants than to estimate the economic factors. Compared to coal-fired or fission plants, however, the environmental impact should be fairly benign.

A long-term concern of a successful and large-scale OTEC program is the effect of a possible change in the temperature characteristics of the tropical ocean. Climate changes can be influenced by changes in atmospheric or oceanic temperatures, but there is little evidence as to how serious a given change in the surface temperature would be. This is an important area for further study. However, it is a distant concern since generation of the entire electrical requirements of the U.S. from the thermal energy of the Gulf Stream would cause a drop of only a fraction of 1°F.

There are both potential advantages and disadvantages associated with pumping large quantities of cold water to the surface. These waters are rich in nutrients and might, therefore, allow the establishment of fisheries around the plants. The practice would definitely distort the ecological balance, and the new balance must be anticipated and understood. In particular, it will be important not to disrupt the natural life cycles of oxygen-producing algae.

The cold water, however, also contains large amounts of dissolved carbon dioxide which would be released upon warming. Preliminary calculations show that the production of 1 kw-hr of electricity by an OTEC plant would release about one-third as much carbon dioxide as released by the present burning of fossil fuel for the same purpose. Since the change in atmospheric temperature due to the "Greenhouse Effect" brought on by increase in atmospheric CO_2 is one of the long-term outcomes, continued study and a search for ways to lower this effect of OTEC plants will have high priority.

SUMMARY

The technique of converting the ocean's thermal energy into electrical energy is one that is understood in theory but not as yet fully tested in practice. Some significant adaptations of and improvements in presently available technologies will be needed in order to satisfy the specialized requirements of this new application and to achieve minimal and competitive costs. Important savings are anticipated from mass production.

An objective of the ERDA research program is to design, construct, and test the components

and subsystems and to construct a pilot plant of about 25 megawatts in the early 1980's. During the course of this development, special attention will be given to problems of corrosion and biofouling, and to the design of the special heat-exchangers which are needed. Methods of delivering the electrical energy and/or of storing and transporting energy-intensive products will be studied, and the environmental impact will be analyzed in detail. Legal and jurisdictional considerations associated with the operation of floating ocean thermal power plants need to be resolved.

The major turning points for the development of the ocean thermal system will be the decision to construct the 25 Mw floating power plant, and the decision to enlarge the plant to a 100 Mw demonstration power plant. The decision on whether to construct land and sea test facilities will be made by 1977. Based on those results, ERDA will determine early in the 1980's whether or not to construct the 25 Mw floating prototype power plant. And, by the mid 1980's, the decision will be made on whether to construct the four advanced power modules in order to convert such a prototype plant to a 100 Mw demonstration plant.

Federal funding for the OTEC program has gone from $700,000 in FY1974 to $6 million in FY 1976, and is projected to go to nearly $47 million in 1980 if the demonstration plant is approved for construction.

The future levels of funding and the anticipated contribution of this source of energy depend on the successful completion of the preliminary steps described above. If all tests prove out successfully, a 100 Mw plant may be operating in 1985 and mass production may be underway. If the tests are negative, or the money needed for testing and development is not forthcoming, this exciting idea may simply remain on the drawing board. In either case, the knowledge gained in OTEC research may contribute to the development of other technologies (e.g., the thermal discharges of conventional power plants) and the ocean's thermal energy will remain to tempt the engineer and the dreamer.

REFERENCES

1. "Solar Sea Power," Clarence Zener, Physics Today 26: 48-53, January 1973.
2. "Energy from the Sea," Parts I, II and III, Popular Science, May, June, July, 1975.
3. "Ocean Thermal Energy Conversion," Robert Cohen (pp. 218-220) in Energy and Man: Technical and Social Aspects of Energy, M. Granger Morton, editor (New York: IEEE Press) 1975.
4. Energy Under the Ocean: A Technology Assessment, Don E. Rash, et. al. (Norman, Oklahoma: University of Oklahoma Press) 1973.
5. "Power, Fresh Water and Food from the Sea," Harry Davitian and William McLean, Science 184: 938, May 31, 1974.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

unit 4
energy harnessing systems and newton's laws

LECTURE NOTES

UNIT FOUR DEALS PRIMARILY WITH CONVERTERS OF ALL TYPES, AN AREA THAT TRADITIONAL POWER MECHANICS HAS DEALT WITH IN A LIMITED FASHION. IT IS IMPORTANT TO EMPHASIZE, ESPECIALLY IN AN ENERGY CONSCIOUS WORLD THAT THERE ARE CONVERSION DEVICES THAT TRANSFORM VIRTUALLY ANY FORM OF ENERGY TO ANY OTHER FORM, NOT JUST FROM CHEMICAL TO MECHANICAL AS THE MUCH STUDIED INTERNAL COMBUSTION ENGINE.
THE UNIT IS ORGANIZED AS TO THE TYPE OF ENERGY INPUT AND NUMEROUS EXAMPLES ARE GIVEN WHICH ILLUSTRATE CONVERSION TO OTHER FORMS.

CURRICULUM GUIDE OUTLINE:

4.00 ENERGY HARNESSING SYSTEMS AND NEWTON'S LAWS
- 4.10 NONCONVERSION, DIRECT CONVERSION, AND INDIRECT CONVERSIONS
- 4.11 LAW OF CONSERVATION OF ENERGY

IN STUDYING CONVERTERS, IT IS LOGICAL TO FIRST DEFINE CONVERSION AT LEAST BY COMPARISON WITH NONCONVERSION AND INDIRECT CONVERSIONS. VISUAL #1 PROVIDES AN EXAMPLE OF ALL THREE. A WINDMILL WITH A GENERATOR ATTACHED CONVERTS MECHANICAL ENERGY FROM THE WIND TO ELECTRICAL ENERGY. THE SAME WINDMILL, IF USED TO PUMP WATER FOR EXAMPLE, CERTAINLY HARNESSES USEFUL ENERGY BUT DOES NOT CONVERT THE MECHANICAL ENERGY FROM THE WIND TO ANOTHER FORM. THIS IS KNOWN AS NONCONVERSION. FINALLY, AN EXAMPLE OF AN INDIRECT CONVERTER IS SHOWN. THE INTERNAL COMBUSTION ENGINE MUST FIRST CONVERT THE CHEMICAL ENERGY OF THE GASOLINE TO THE FORM OF HEAT. THIS ENERGY IN THE FORM OF HEAT MUST IN TURN BE CONVERTED TO MECHANICAL ENERGY. THUS CHEMICAL ENERGY WAS INDIRECTLY CONVERTED TO MECHANICAL ENERGY.

IN STUDYING CONVERSION IT IS ALSO USEFUL TO RECALL THE LAW OF CONSERVATION OF ENERGY WHICH STATES THAT ENERGY CAN NEITHER BE GAINED NOR LOST, IT IS SIMPLY CONVERTED FROM ONE FORM TO ANOTHER, POTENTIAL OR KINETIC. A USEFUL EXERCISE IN CLASS MIGHT BE TO LIST A NUMBER OF SITUATIONS WHERE ENERGY APPEARS TO BE LOST, BUT IS MERELY CONVERTED. FOR EXAMPLE WHAT HAPPENS TO THE MECHANICAL ENERGY OF THE CAR WHEN IT IS BRAKED TO A STOP? THE BRAKES CONVERTED THE ENERGY TO HEAT, JUST A DIFFERENT FORM OF ENERGY. WHAT HAPPENS TO THE ENERGY OF A WATERFALL WHEN IT REACHES THE BOTTOM? IT IS CONVERTED TO HEAT. THE LAW OF CONSERVATION OF ENERGY PRE-DATES EINSTEIN'S EQUATION $E=MC^2$. THUS NUCLEAR ENERGY IS AN EXCEPTION IN THAT MATTER AND ENERGY ARE INTERCHANGEABLE, BUT EVEN IN THIS RELATIONSHIP THERE IS CONSERVATION. THERE IS AN ADDITIONAL CONVERSION BETWEEN MATTER AND ENERGY, NOT JUST FROM ONE FORM OF ENERGY TO ANOTHER.

AN EXCELLENT NO COST DIRECT CONVERSION DEVICE THAT CAN BE MADE FROM MATERIALS IN THE LAB OR AROUND THE HOME IS SHOWN IN VISUAL #2. IT IS INTERESTING TO WATCH AND COULD EVEN AROUSE ENOUGH INEREST FOR A CONTEST AMONG STUDENTS. THE DEVICE CONVERTS THE SUNS ENERGY, LIGHT AND HEAT DIRECTLY TO MECHANICAL ENERGY. THE OPERATION OF THE DEVICE IS SHOWN AT THE TOP OF THE VISUAL. TWO 14 OUNCE FOAM CUPS ARE GLUED TO A ¼ INCH DOWEL AT THE CENTER. THE LEFT CUP IS ALSO FASTENED SOLID TO THE DOWEL BY A DISK CUT FROM A FOAM PLATE SUCH AS A MEAT PACKAGE. THUS THELEFT CUP IS RIGID, WHILE THE RIGHT CUP IS FREE TO MOVE AT THE END.

ABOUT 12 ½INCH STRIPS OF PRE-STRETCHED BLACK PLASTIC STRIPS FROM A GARBAGE BAG ARE GLUED AROUND THE CIRCUMFERENCE OF THE CUPS. THE SUN HEATS THE STRIPS ON TOP CAUSING THEM TO CONTRACT RAISING A WEIGHT (PLASTIC COFFEE CAN LID) WHICH CONTINUALLY (FALLS) AROUND AND RAISES OTHER STRIPS TO THE TOP WHERE THEY ARE HEATED. THE DIAGRAM IS AN EXXAGERATED VIEW OF THE CONTRACTION CAUSED BY HEAT. FOR DETAILS OF CONSTRUCTION SEE PP. 126, 128, FEBRUARY, 1980, POPULAR SCIENCE MAGAZINE.

CURRICULUM GUIDE OUTLINE

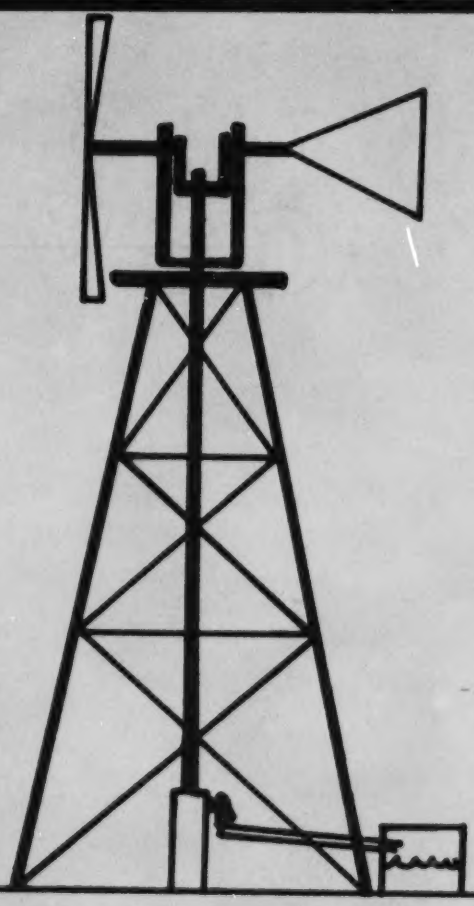
- 4.20 CHEMICAL ENERGY INPUT
  - 4.21 FUEL CELLS
  - 4.22 BATTERIES
  - 4.23 FUSION
  - 4.24 FISSION
  - 4.25 SUN
  - 4.26 CHEMICAL HEATERS
  - 4.27 INTERNAL COMBUSTION ENGINES
    - 4.271 ROCKET
    - 4.272 JET
    - 4.273 TURBOJET
    - 4.274 FANJET
    - 4.275 TURBO-PROP
    - 4.276 DIESEL
    - 4.277 GAS AND GAS TURBINES
  - 4.28 EXTERNAL COMUSTION ENGINE
    - 4.281 STEAM (PISTON AND TURBINE)
    - 4.282 STIRLING
  - 4.29 CHEMICAL EXPLOSIVES
    - 4.291 BLACK POWDER
    - 4.292 DETONATING EXPLOSIVES

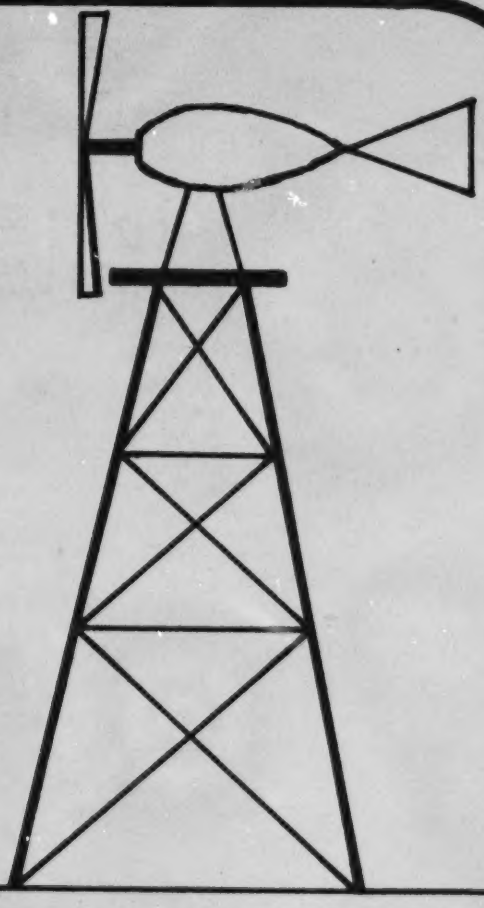
AS CAN BE SEEN FROM THE CURRICULUM GUIDE OUTLINE THERE IS A FANTASTIC VARIETY OF CONVERTERS THAT UTILIZE CHEMICAL ENERGY AS INPUT. THE FUEL CELL CONVERTS BY A CHEMICAL REACTION FOSSIL FUEL, ALCOHOL OR HYDROGEN DIRECTLY TO ELECTRICAL ENERGY. THE BATTERY CONVERTS CHEMICAL ENERGY TO ELECTRICAL ENERGY DIRECTLY IN A REVERSIBLE OR NON-REVERSIBLE REACTION. FUSION, FISSION, AND THE SUN AS ALREADY DISCUSSED CONVERT CHEMICAL ENERGY DIRECTLY TO HEAT ENERGY. CHEMICAL HEATERS CONVERT FOSSIL FUELS DIRECTLY TO HEAT. INTERNAL AND EXTERNAL COMBUSTION ENGINES CONVERT CHEMICAL ENERGY INDIRECTLY TO MECHANICAL ENERGY, AND EXPLOSIVES CONVERT CHEMICAL ENERGY INDIRECTLY TO HEAT TO MECHANICAL ENERGY.

THE FUEL CELL IS ESPECIALLY NOTEWORTHY AND DESERVING OF DISCUSSION PRIMARILY BECAUSE OF ITS EXTREMELY HIGH EFFICIENCY (UPWARDS OF 80%) WHICH IS ATTRACTIVE WHEN COMPARED TO THE 15-20% EFFICIENCY OF THE INTERNAL COMBUSTION ENGINE, LOW POLLUTION - ITS BY PRODUCT IS WATER, AND THE FACT THAT IT CAN BURN HYDROGEN, A RENEWABLE FUEL. UNFORTUNATELY, THE FUEL CELL IS STILL SO EXPENSIVE THAT ITS USE IS LIMITED TO SPACE AND SIMILIAR APPLICATIONS. WHILE A DEMONSTRATION CELL IS RELATIVELY

UNIT # 4 TOPIC 4.10 CONVERSION, NONCON. & INDCON.

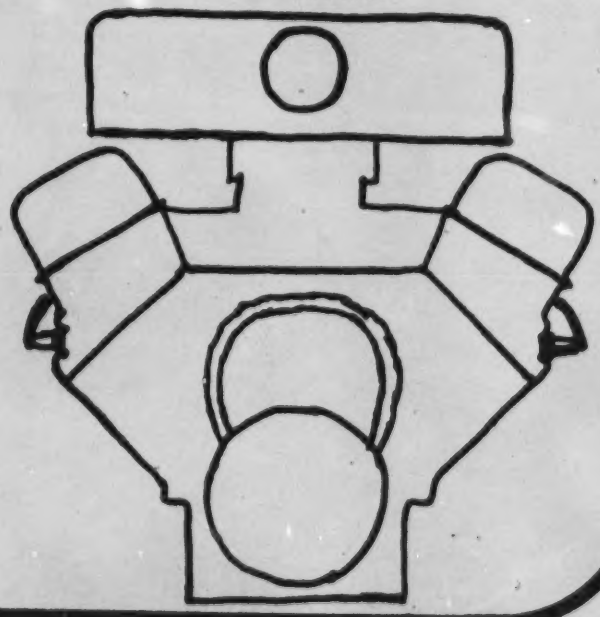
VISUAL # 1





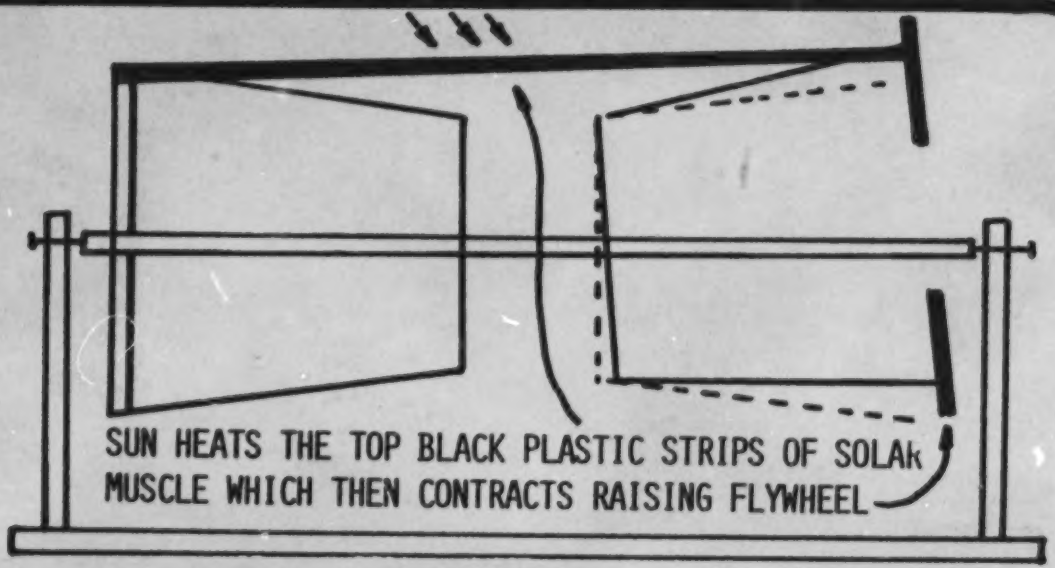
NON -- CONVERSION MECHANICAL TO MECHANICAL

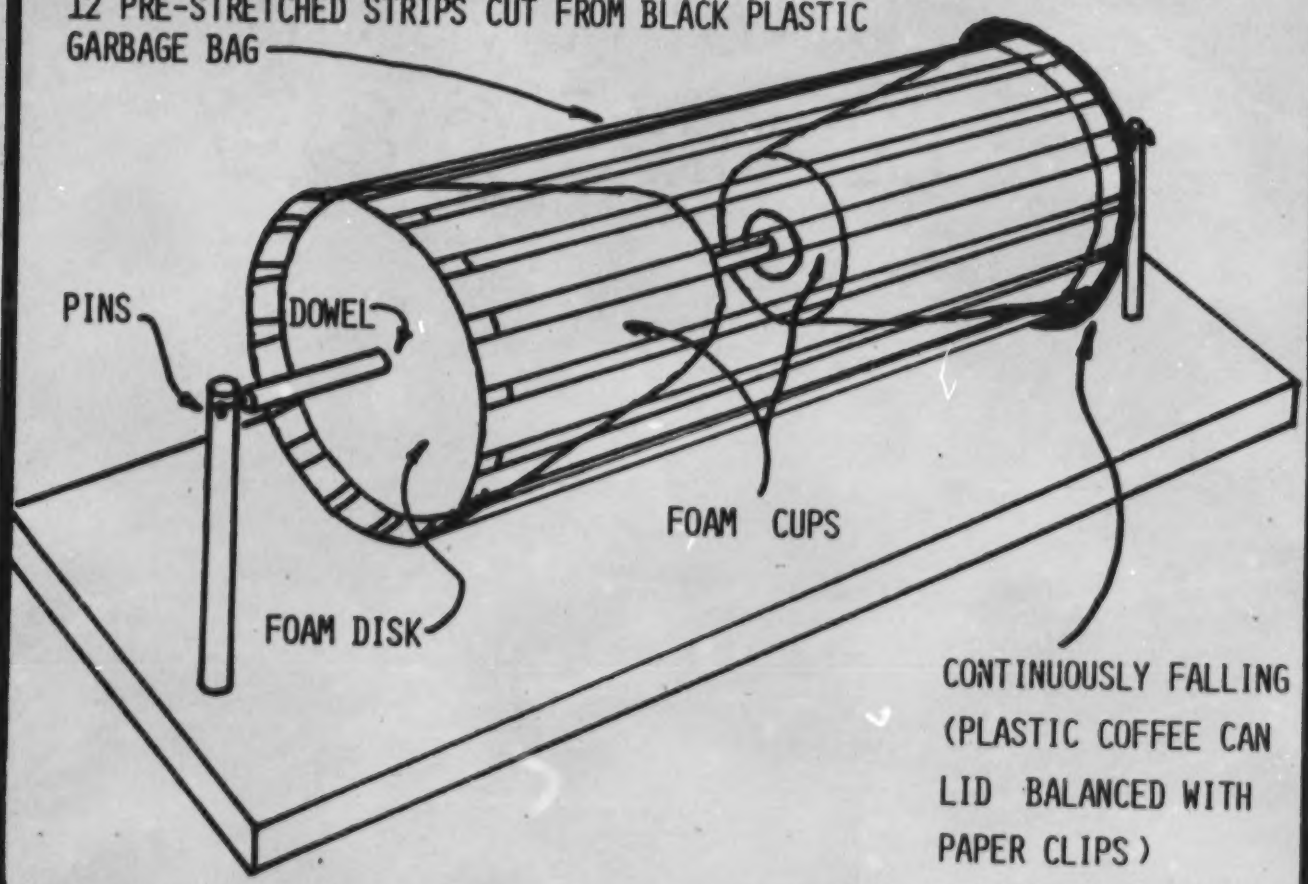
CONVERSION MECHANICAL TO ELECTRICAL



INDIRECT CONVERSION --
CHEMICAL TO HEAT TO MECHANICAL

VISUAL # 2





"SOLAR MUSCLE" DIRECT CONVERSION SOLAR ENGINE - HEAT TO MECHANICAL

EASY TO CONSTRUCT FOR CLASSROOM USE, THE MATERIALS ARE SOMETIMES DIFFICULT TO COME BY. THERE ARE SEVERAL APPROACHES THAT CAN BE FOLLOWED BY AN AMBITIOUS TEACHER. WITH THE HELP OF A CHEMISTRY TEACHER AND AN ARTICLE PUBLISHED IN SCIENTIFIC AMERICAN MAGAZINE, NOVEMBER, 1967, IN THE AMATEUR SCIENTIST SECTION ONE CAN CONSTRUCT A DEMONSTRATION CELL SIMILIAR TO THE ONE SHOWN IN VISUAL #3. THIS CELL AND MOST OTHERS AVAILABLE ARE BASED ON PUBLICATIONS ORIGINALLY MADE BY THE ESSO RESEARCH AND ENGINEERING COMPANY IN THE EARLY 1960s. THE TEXT AND WORKBOOK WALKER (SEE APPENDIX A) ALSO CONTAIN USEFUL INFORMATION ON CONSTRUCTING A CELL. A THIRD ALTERNATIVE IS TO PURCHASE A COMPLETE DEMONSTRATOR SOLD BY BROADHEAD - GARRETT FOR UNDER $200.

REFERING AGAIN TO VISUAL #3, THE BASIC CELL SHOWN USES METHYL ALCOHOL AS A FUEL. IN THE PRESENCE OF PLATINUM AS A CATALYST, OXYGEN FROM THE AIR COMBINES WITH THE ALCOHOL TO PRODUCE FREE ELECTRONS, WATER, AND FORMIC ACID. A HYDROGEN CELL OF COURSE HAS ONLY WATER AS A BY PRODUCT. THE EXACT CHEMICAL REACTIONS ARE GIVEN ON THE VISUAL.

AMONG THE EASIEST AND QUICKEST CONVERTER EXPERIMENTS TO PRODUCE IN THE LAB ARE THOSE INVOLVING CELLS AND BATTERIES. IT IS ALSO QUITE MOTIVATING TO WATCH A LIGHT EMITTING DIODE, LIGHT BULB OR METER RESPOND TO THE CURRENT FROM A STUDENT MADE BATTERY. VISUAL #4 SHOWS SOME OF THE INFINITE VARIETY OF CELLS AND BATTERIES THAT CAN BE CONSTRUCTED WITH READILY AVAILABLE MATERIALS. ANOTHER OPPORTUNITY TO BE EXPLORED IS THE EXTREMELY HIGH POWER BATTERY THAT CAN BE REMOVED FROM USED POLAROID SX-70 OR ONE-SHOT FILM PACKS. EVEN WHEN USED, IT PUTS OUT ABOUT 6 VOLTS AND HAS CONSIDERABLY MORE PUNCH THAN FOUR AA CELLS. ITS EXTRA THIN PACKAGE (.18 INCH) LENDS ITSELF TO MANY (HIDDEN) EXPERIMENTS.

ANOTHER CHEMICAL ENERGY INPUT CONVERTER THAT HAS LONG BEEN USED AS A MOTIVATOR IN ENERGY POWER CLASSES IS THE ROCKET ENGINE AND MODEL ROCKETRY. WRITE ESTES INDUSTRIES FOR A CATALOGUE (SEE APPENDIX B. ALSO BROADHEAD-GARRETT MARKETS ROCKET ENGINE TRAINERS IF A MORE DETAILED STUDY OF ROCKET ENGINE PERFORMANCE IS DESIRED.

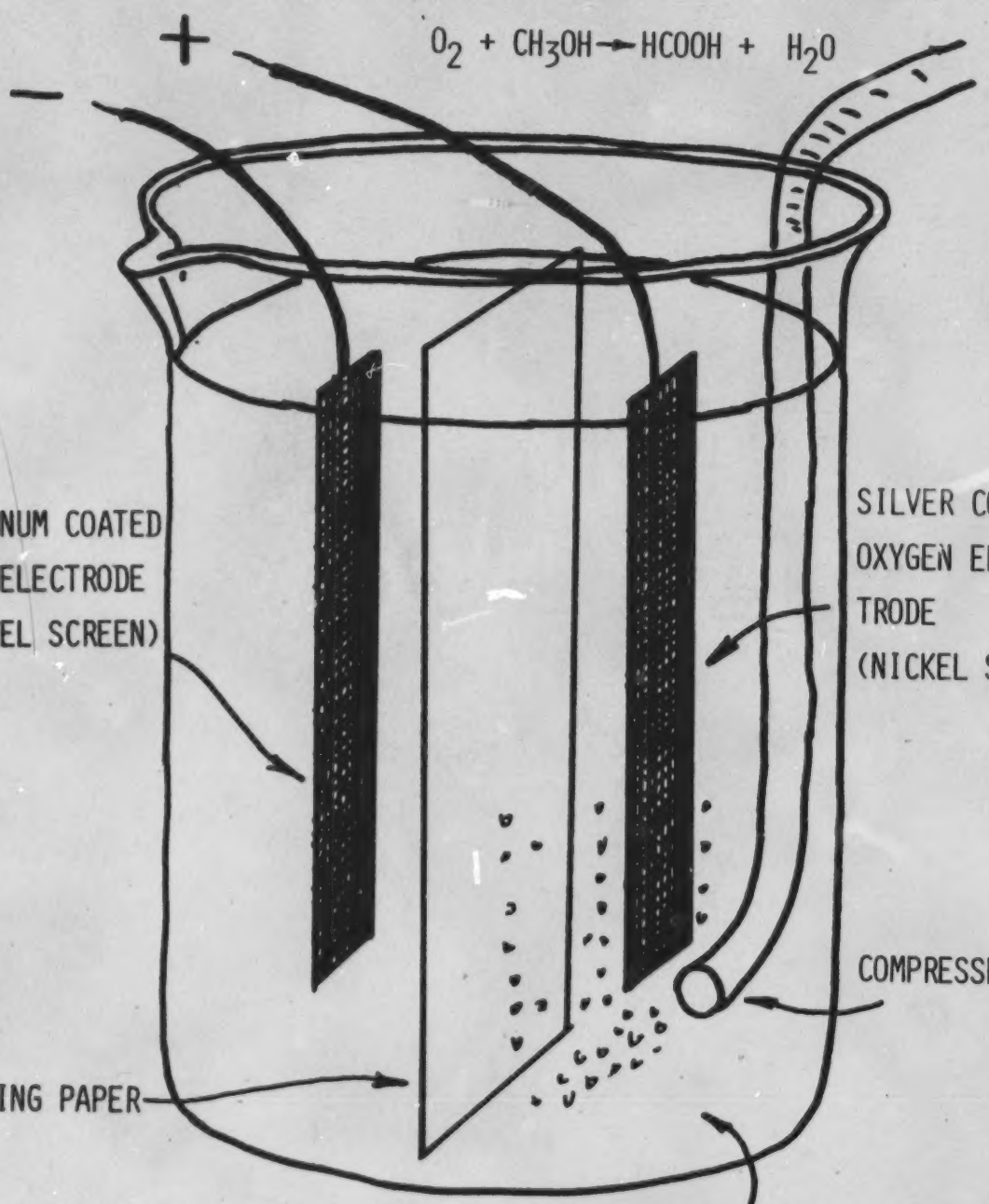
THE STIRLING ENGINE IS LISTED IN THE OUTLINE AS A CHEMICAL INPUT CONVERTER, WHICH IT IS , BUT IT CAN ALSO CONVERT ENERGY FROM THE SUN DIRECTLY TO MECHANICAL ENERGY BY USE OF A FRESNEL LENS OR PARABOLIC MIRROR. THE STIRLING ENGINE HAS MANY ADVANTAGES INCLUDING; LOW TO NO POLLUTION, EXTREMELY HIGH THEORETICAL EFFICIENCY OF NEARLY 60%, WITH A DEMONSTRATED EFFICIENCY OVER 40%, AND WILL BURN ANY FUEL OR USE NEARLY ANY SOURCE OF HEAT. THE ONLY APPARENT DISADVANTAGE IS THE HIGH COST OF MANUFACTURE AND RETOOLING WHICH HAS CAUSED DETROIT TO SHUN THE STIRLING. AT ANY RATE THE ENGINE HAS BEEN TESTED IN A FULL SIZE FORD TOURINO AND HAS PROVEN FEASIBLE-EXCEPT FOR COST. MOST WELL EQUIPPED POWER LABS HAVE A SMALL DEMONSTRATION MODEL SIMILIAR TO THAT SHOWN IN VISUAL #5. THIS MODEL WAS MADE FROM PLANS PUBLISHED IN POPULAR SCIENCE IN 1961, AND AGAIN IN JUNE, 1965. SIMILIAR UNITS ARE AVAILABLE FROM MANY SOURCES RANGING IN PRICE FROM $30 TO OVER $100. ALL ARE OPERATIONALLY SIMILIAR TO THE ENGINE PATENTED BY ROBERT STIRLING IN SCOTLAND IN 1816. THE PHILIPS COMPANY OF HOLLAND HAS BEEN THE PRINCIPLE DEVELOPER OF THE STIRLING AND HAS BEEN RESPONSIBLE FOR MOST IMPROVEMENTS DURING THE LAST THIRTY YEARS. BASICALLY, MOST OF THE ADVANTAGES OF THE STIRLING ARE DUE TO THE FACT THAT IT IS AN EXTERNAL COMBUSTION ENGINE, WHEREBY THE COMBUSTION PROCESS CAN BE CONTROLLED CAREFULLY AND AS A RESULT IS LOW IN POLLUTION. REFER TO VISUAL #5 FOR A DESCRIPTION OF ITS OPERATION. AIR INSIDE THE DISPLACER CYLINDER IS HEATED BY AN EXTERNAL FLAME OR THE

CONT'D ON 4-9

VISUAL # 3

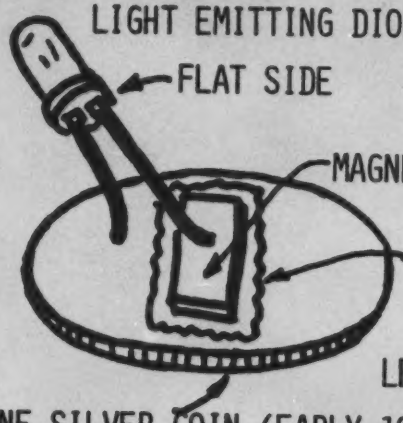
LABORATORY FUEL CELL

OXYGEN + METHYL ALCOHOL = FORMIC ACID + WATER + FREE ELECTRONS



AT FUEL ELECTRODE: $CH_3OH + 4OH^- \rightarrow HCOOH + 3H_2O + 4E$

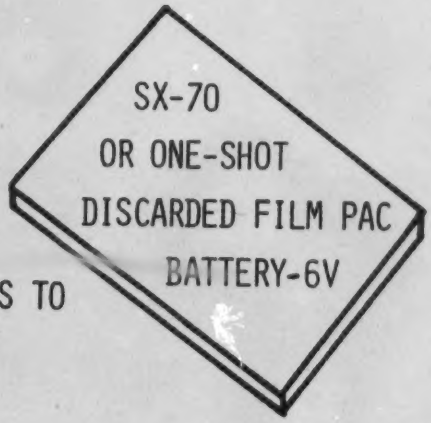
AT OXYGEN ELECTRODE: $O_2 + 2H_2O + 4E \rightarrow 4OH^-$



GENUINE SILVER COIN (EARLY 1960's)

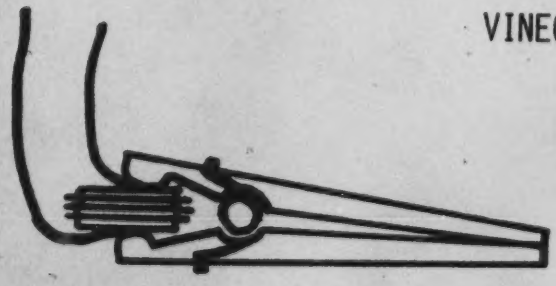
SOME ELECTRODE COMBINATIONS TO EXPERIMENT WITH:

	VOLTS
SILVER/MAGNESIUM	____
COPPER/MAGNESIUM	____
NICKEL/MAGNESIUM	____
SILVER/ZINC	____
SILVER /ALUMINUM	____
NICKEL/ZINC	____
ALUMINUM/MAGNESIUM	____
COPPER/ZINC	____



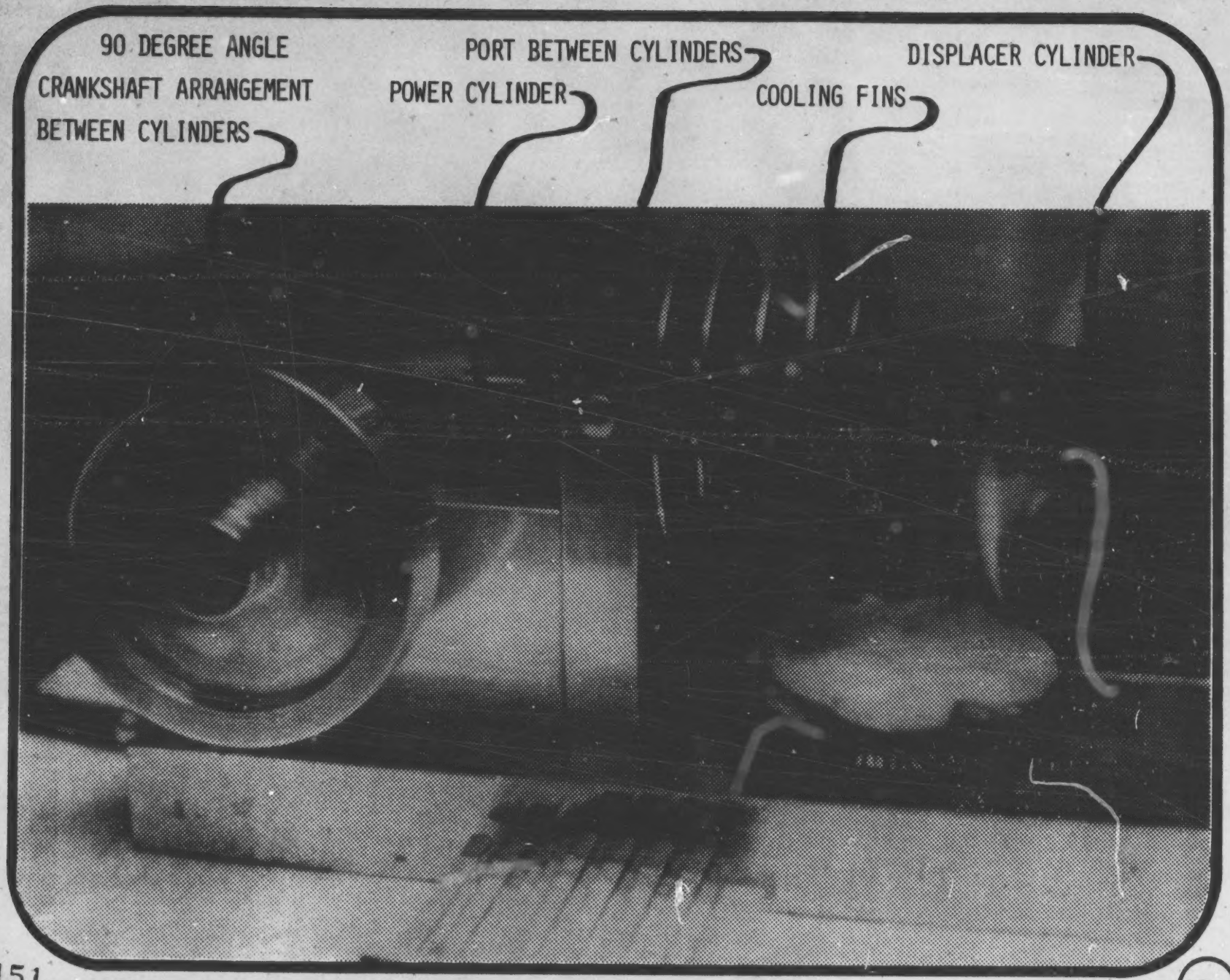
SOME ELECTROLYTES TO EXPERIMENT WITH:

- SALT WATER
- SOFT DRINKS (COKE ETC.)
- LEMON JUICE
- VINEGAR



STACK OF PENNYS AND ZINK PLATED ELECTRICAL KNOCK OUT PLUGS WITH SALT WATER SOAKED PAPER TOWEL IN BETWEEN EACH PLATE

LEMON WITH COPPER AND ZINC ELECTRODES


90 DEGREE ANGLE
CRANKSHAFT ARRANGEMENT
BETWEEN CYLINDERS
POWER CYLINDER
PORT BETWEEN CYLINDERS
COOLING FINS
DISPLACER CYLINDER

VISUAL # 5

SUN. AS A RESULT, IT EXPANDS AND SLIDES PAST THE DISPLACER PISTON WHICH DOES NOT TOUCH THE CYLINDER. IT PASSES THROUGH THE PORT AS SHOWN AND ENTERS THE POWER CYLINDER PUSHING THE POWER PISTON BACK. NOW, AS A RESULT OF THE 90 DEGREE CRANKSHAFT TIMING, THE DISPLACER PISTON IS ON ITS WAY BACK TOWARD THE POWER PISTON AS IT STARTS FORWARD LEAVING NO ROOM FOR THE AIR EXCEPT TO SLIDE PAST THE DISPLACER FORWARD WHERE IT IS HEATED AND STARTS THE CYCLE ALL OVER. THIS ACTION IS ALSO ASSISTED BY THE FACT THAT IT IS MUCH COOLER NEAR THE POWER PISTON AND THIS CAUSES THE AIR TO CONTRACT "PULLING" THE POWER PISTON FORWARD.

A STIRLING TRAINER AND OTHER TRAINERS AND AUDIOVISUALS ARE AVAILABLE FROM MEGATECH (SEE APPENDIX). ALSO BROADHEAD-GARRETT HANDLES A NUMBER OF TRAINERS INCLUDING EXTERNAL COMBUSTION STEAM ENGINES. EDMUND SCIENTIFIC LISTS A FUEL AND A SOLAR STIRLING (SEE APPENDIX)

REFER ALSO TO THE "SCIENCE ACTIVITIES IN ENERGY" SERIES WHICH SHOULD BE ATTACHED TO THIS HANDBOOK. IF IT IS NOT, SEE APPENDIX OR CALL THE STATE ENERGY MANAGEMENT AND CONSERVATION OFFICE 701-224-2250.

CURRICULUM GUIDE OUTLINE

- 4.30 MECHANICAL ENERGY INPUT
  - 4.31 PNEUMATIC DRIVEN
    - 4.311 WIND TURBINE
      - 4.3111 AIR MOTOR
      - 4.3112 WINDMILL
    - 4.312 SAIL AND SAILBOATS
    - 4.313 PISTON DEVICES
      - 4.3131 JACK HAMMER
  - 4.32 HYDRAULIC DRIVEN
    - 4.321 WATER TURBINE
    - 4.322 HYDRAULIC MOTOR
    - 4.323 PISTON DEVICES
      - 4.3231 SHOCK ABSORBERS OF ADJUSTABLE SCREEN DOOR CLOSERS
      - 4.3232 HYDRAULIC RAM
  - 4.33 PIEZOELECTRIC EFFECT
  - 4.34 ELECTRIC GENERATORS AND ALTERNATORS

MOST OF THE DEVICES LISTED IN THE CURRICULUM GUIDE OUTLINE ARE NON-CONVERSION DEVICES, NEVER-THE-LESS, THEY HARNESS ENERGY FOR MANS USE. COUNTLESS DEVICES CAN BE BROUGHT TO THE LAB FOR DEMONSTRATION. A COMPLETE HYDRAULIC SYSTEM CAN BE SALVAGED AND ASSEMBLED IN THE LAB FROM A CARS POWER STEERING SYSTEM. AN ELECTRIC MOTOR CAN BE ATTACHED TO THE PUMP VIA THE PULLY AND THE ENTIRE SYSTEM DEMONSTRATED INCLUDING THE DOUBLE ACTING CYLINDER FOUND ON OLDER CARS. ONCE THE ELECTRIC MOTOR IS ATTACHED, THE SYSTEM BECOMES A CONVERTER, ELECTRIC ENERGY TO MECHANICAL ENERGY. AN INTERESTING DEVICE THAT CAN EASILY BE BUILT FROM AN INNER TUBE VALVE STEM AND ¼ INCH BRASS TUBING IS THE VORTEX TUBE. THE VORTEX TUBE IS A LITTLE KNOWN CONVERTER THAT CHANGES MECHANICAL ENERGY (COMPRESSED AIR) TO HEAT ENERGY. AS A MATTER OF FACT, ONE END GETS EXTREMELY HOT - AS HIGH AS 160 DEGREES F. FOR A COMMERCIAL MODEL, (71° C)

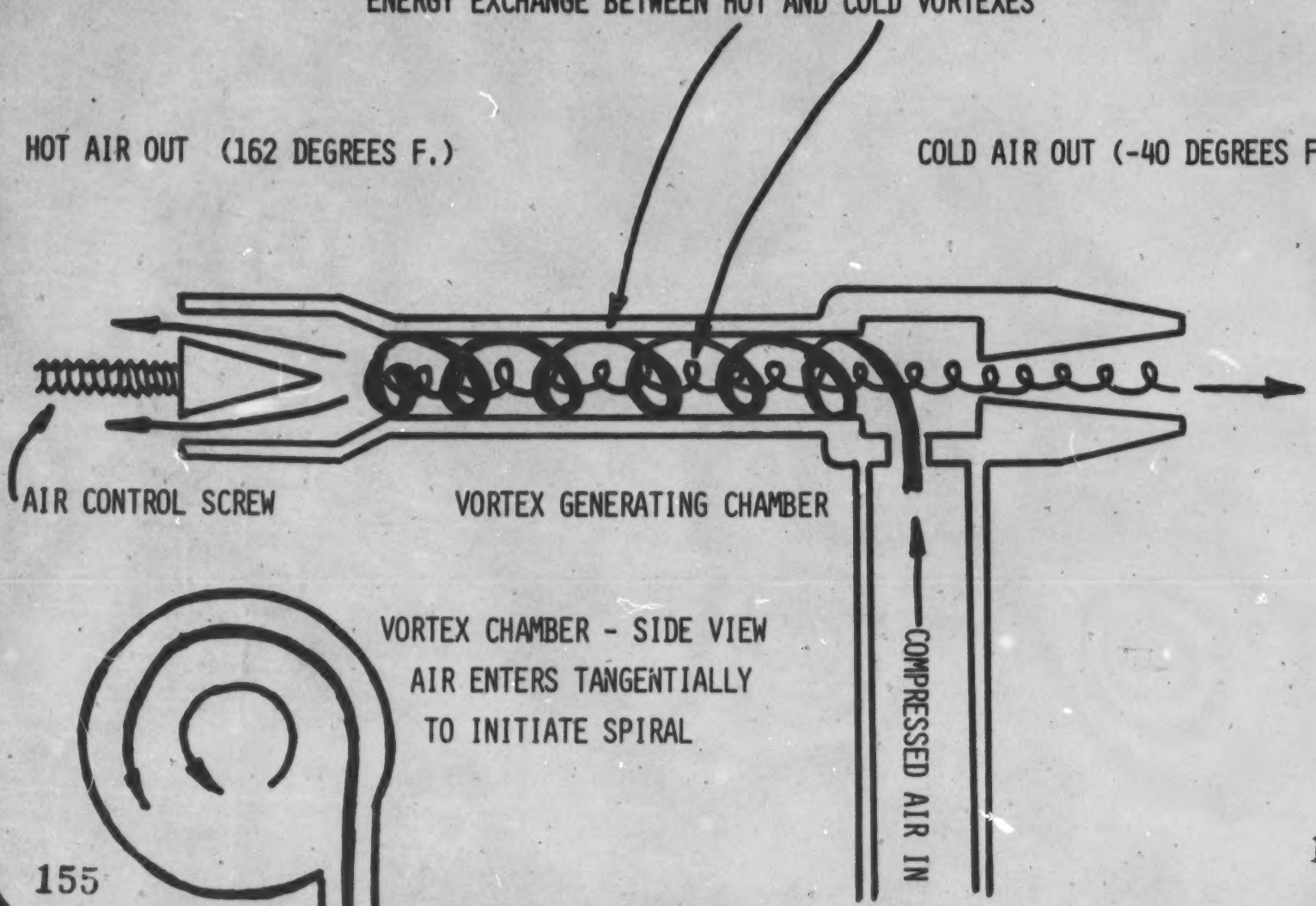
AND THE OTHER END GETS EXTREMELY COLD - AS LOW AS -40 DEGREES F. (-40°C). THE EXPLANATION OF THE OPERATING PRINCIPLE OF THE VORTEX TUBE IS QUITE LENGTHY AND THE PRINCIPLE ITSELF IS NOT TOTALLY UNDERSTOOD. FOR A COMPLETE DESCRIPTION REFER TO POPULAR SCIENCE MAGAZINE, OCTOBER, 1976, P123. PLANS FOR BUILDING A MODEL ARE INCLUDED. IF YOU DESIRE TO PURCHASE A DEMONSTRATION MODEL WRITE: VORTEC CORP. 4511 READING ROAD., CINCINNATI, OHIO 45229. REFER TO VISUAL #6 FOR ASSISTANCE IN EXPLAINING DEVICE TO CLASS. THE VORTEX TUBE IS USED TO COOL DRILL BITS WHERE LIQUIDS ARE UNACCEPTABLE (DRILLING PLASTIC), PROTECTIVE HOT SUITS AND OTHER APPLICATIONS WHERE AIR CONDITIONING AND REFRIGERATION IS NOT POSSIBLE OR ECONOMICAL.

THE PIEZOELECTRIC CRYSTAL IS A DEVICE THAT CONVERTS MECHANICAL ENERGY TO ELECTRICAL ENERGY. THE EFFECT IS ALSO REVERSIBLE, THAT IS, IF ELECTRICAL ENERGY IS APPLIED TO THE CRYSTAL, MECHANICAL ENERGY IS PRODUCED. WHILE THIS PHENOMENON WOULD BE MOST APPROPRIATELY COVERED IN THE NEXT TOPIC, ELECTRICAL ENERGY INPUT, IT WILL BE COVERED HERE FOR CONVENIENCE. PIEZO ELECTRIC PROPERTIES ARE POSSESED BY THREE NATURAL CRYSTALLINE MATERIALS: ROCHELLE SALT, TOURMALINE AND QUARTZ. SYNTHETIC PEIZOELECTRIC DEVICES ARE CONSTRUCTED IN ALMOST ANY SHAPE BY FIRING A CERAMIC POWDER, BARIUM TITANATE, IN A FURNACE IN WHICH A HIGH VOLTAGE IS INDUCED CAUSING A CRYSTALLINE STRUCTURE TO BE FORMED. THERE ARE DOZENS OF EVERYDAY APPLICATIONS OF THESE MATERIALS THOUGH THEY ARE USUALLY WELL CONCEALED WITHIN DEVICES AND ARE NOT RECOGNIZED BY THE GENERAL PUBLIC. A FEW EXAMPLES: QUARTZ CRYSTALS ARE USED IN DIGITAL WATCHES TO STABILIZE TIMEKEEPING SINCES THEY VIBRATE AT VERY PRECISE FREQUENCIES, THEY ARE USED IN PHONO CARTRIDGES TO CONVERT MECHANICAL VIBRATIONS FROM THE RECORD TO ELECTRICAL PULSES THUS THE TERM "CERAMIC CARTRIDGE, THEY ARE USED IN SMALL HEADPHONES AND MICROPHONES, THEY WERE USED FOR A TIME AS AN IGNITION SYSTEM FOR SMALL ENGINES WHEREIN A CAM SQUEEZED A CERAMIC PELLET PRODUCING A HIGH VOLTAGE, THEY ARE USED BY DENTISTS, DRAFTSMEN, ARTISTS, JEWELERS AND OTHERS FOR CLEANING DELECATE PENS AND PARTS - A HIGH FREQUENCY AMPLIFIER DRIVES A CRYSTAL ATTACHED TO A STAINLESS STEEL TANK PRODUCING ULTRA-SONIC CLEANING ACTION, THEY ARE USED IN SONAR AND UNDERWATER LISTEN-ING DEVICES.

ULTRASONIC CLEANERS CAN BE PURCHASED FROM DRAFTING AND GENERAL SUPPLY HOUSES FOR $30 - $100. CENTRAL SCIENTIFIC (SEE APPENDIX) OFFERS A NUMBER OF DEVICES RANGING FROM UNDER $20 FOR A TORCH LIGHTER TO OVER $100. REFER TO VISUAL #7 FOR ASSISTANCE IN EXPLAINING THE ACTION OF THE CRYSTAL. AT THE TOP OF THE VISUAL MECHANICAL DEFORMATION OF THE CRYSTAL CAUSES A HIGH VOLTAGE TO BE PRODUCED (SEVERAL THOUSAND VOLTS). AT THE BOTTOM OF THE VISUAL, A HIGH FREQUENCY ALTERNATING VOLTAGE IS APPLIED TO THE CRYSTAL CAUSING DEFORMATION, OR MECHANICAL ENERGY.

NUMEROUS IDEAS FOR ACTIVITIES FOR MECHANICAL ENERGY INPUT CAN BE FOUND IN THE ATTACHED "SCIENCE ACTIVITIES IN ENERGY - WIND ENERGY" INCLUDING WIND DRIVEN GENREATORS.

VORTEX TUBE ENERGY CONVERTER - MECHANICAL TO HEAT (COLD)



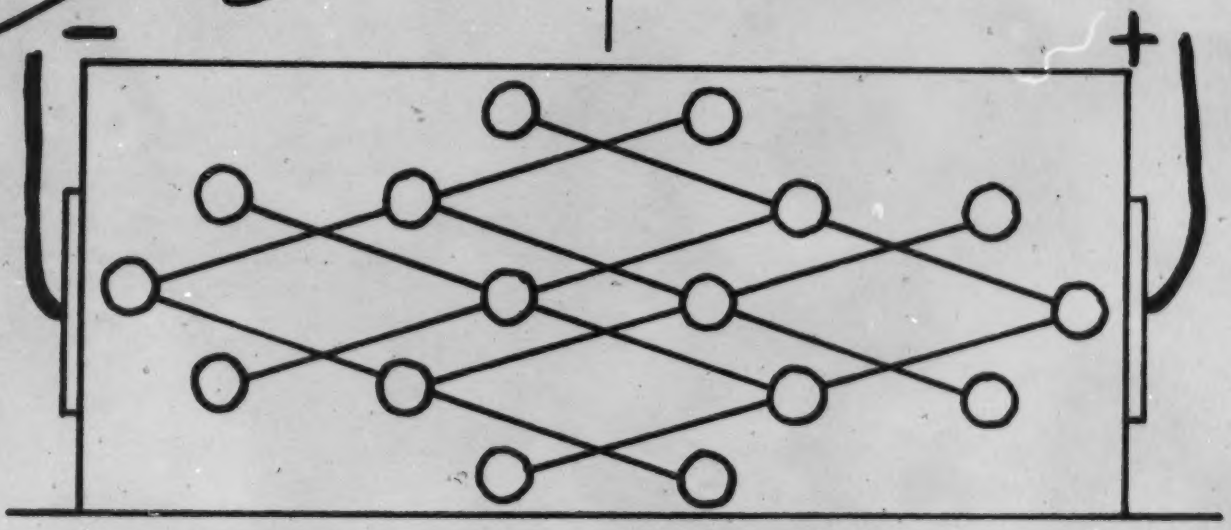
VISUAL # 6

7

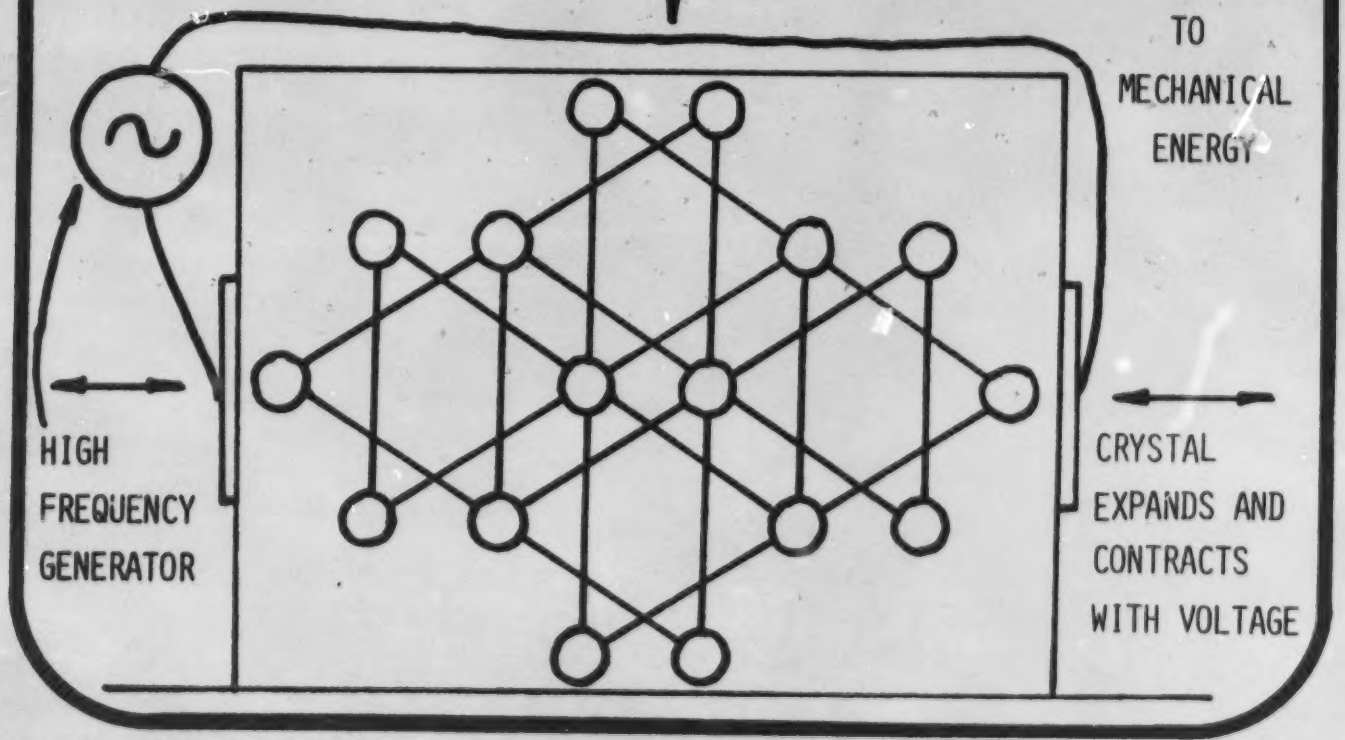
VISUAL #

PIEZOELECTRIC CRYSTAL AS AN
ENERGY CONVERTER - MECHANICAL TO ELECTRICAL

Y - AXIS OF CRYSTAL



PIEZOELECTRIC CRYSTAL AS AN ULTRA SONIC TRANSDUCER - ELECTRIC ENERGY TO MECHANICAL ENERGY

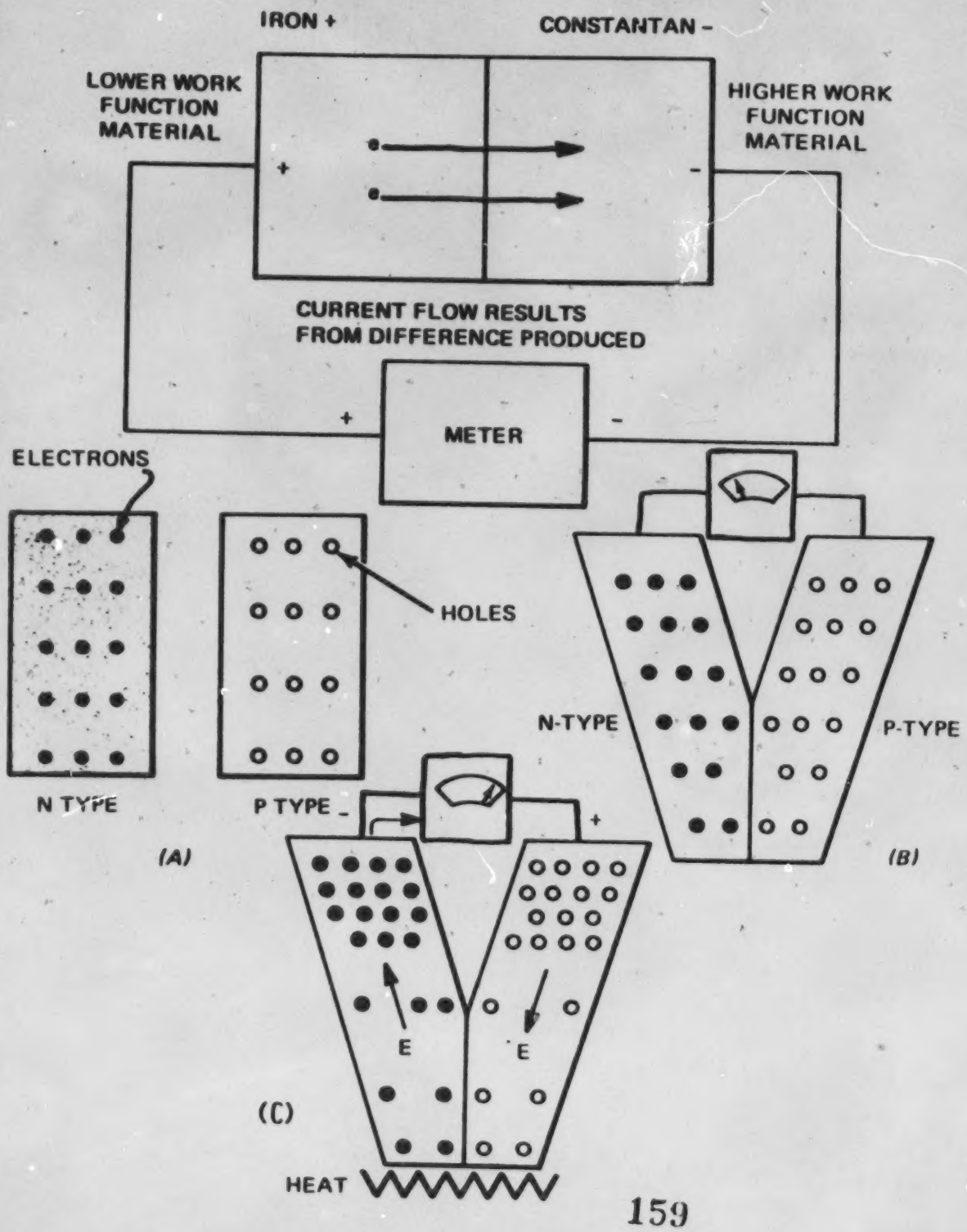


CURRICULUM GUIDE OUTLINE:

4.40 ELECTRICAL ENERGY INPUT
- 4.41 MOTORS
- 4.42 SOLENOIDS
- 4.43 SPEAKERS
- 4.44 NICHROME WIRE HEATING ELEMENT
- 4.45 CRYSTALS
- 4.46 RADIO
- 4.47 TELEVISION
- 4.48 HEATERS
- 4.49 LIGHTS
- 4.410 REFRIGERATOR SYSTEMS
- 4.411 LASER
- 4.412 LIGHT EMITTING DIODE (LED)
- 4.413 VACUUM TUBES
- 4.414 SEMICONDUCTORS
- 4.415 MAGNETOHYDRODYNAMIC GENERATOR
- 4.416 MICROWAVE OVENS
- 4.417 ETC.

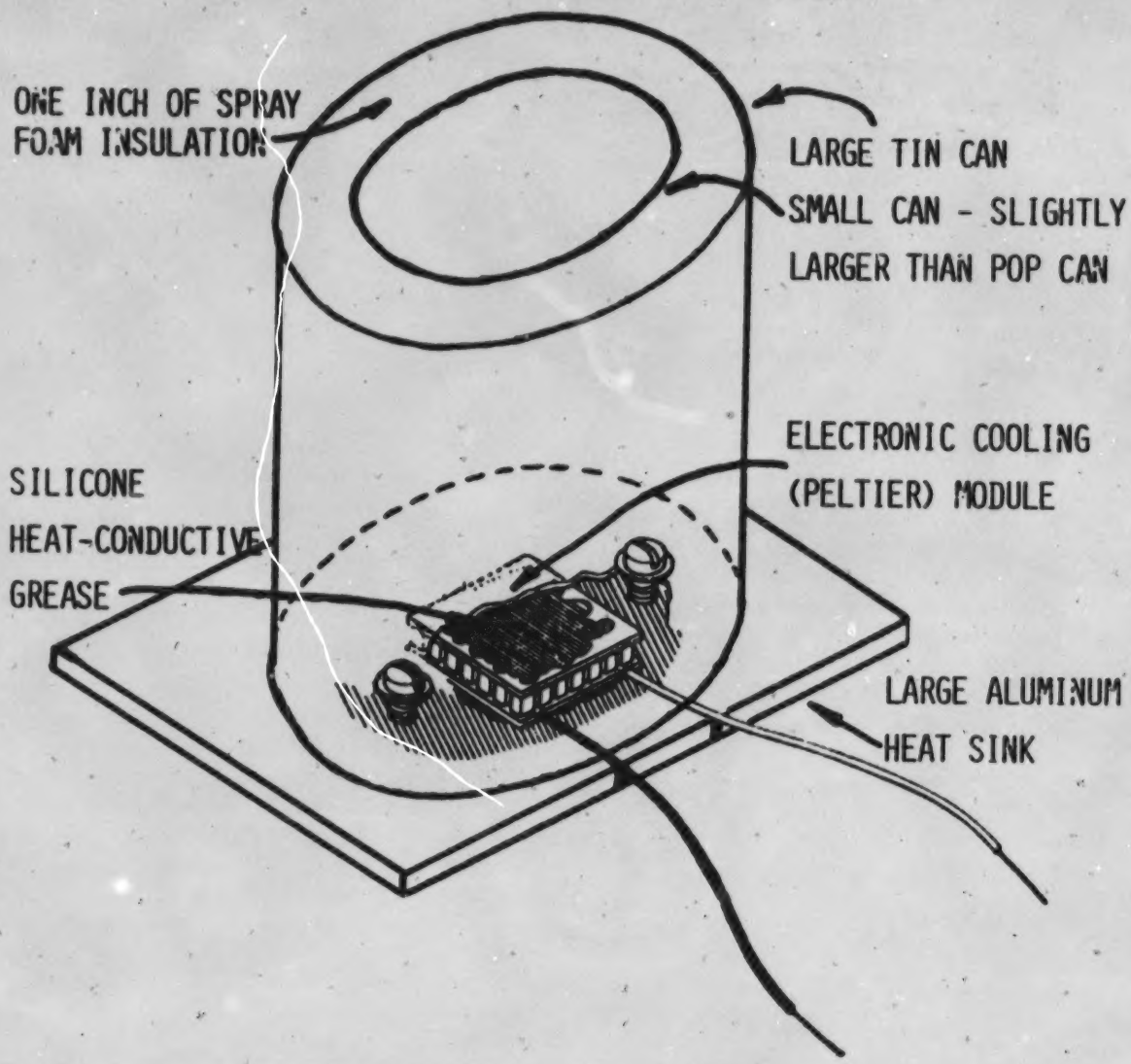
ELECTRICAL ENERGY INPUT CONVERTERS ARE AMONG THE EASIEST TO DISCUSS, DEMONSTRATE, AND TO PROVIDE ACTIVITIES FOR SIMPLY BECAUSE OF THE SHEER ABUNDANCE USED IN THE HOME AND CLASSROOM. REFERING TO THE OUTLINE ABOVE, ELECTRIC MOTORS CAN BE PURCHASED FOR AS LITTLE AS 3 FOR $1 AT LOCAL RADIO SHACK STORES HOBBY SHOPS AND SURPLUS HOUSES. CONSTRUCTING ELECTRIC MOTORS IN CLASS PROVIDES AN EXCELLENT COMPETITIVE AND MOTIVATING ACTIVITY, SEE ATTACHED "SCIENCE ACTIVITIES IN ENERGY - ELECTRICAL ENERGY", THE PRINCIPLE OF THE SOLENOID CAN BE DEMONSTRATED BY PLACING A ONE INCH DIAMETER ROD IN A SALVAGED AUTO STARTER SOLENOID AND ATTACHING THE TERMINALS TO AN AUTO BATTERY, TWO STUDENTS WILL HAVE DIFFICULTY PULLING THEM APART. SPEAKERS ARE AVAILBLE BY THE DOZENS IN SMALL TRANSISTOR RADIOS, NICHROME WIRE HEATING ELEMENTS CAN QUICKLY AND SAFELY BE DEMONSTRATED WITH AN INEXPENSIVE HAIR DRYER, CRYSTALS WERE DISCUSSED IN THE PREVIOUS TOPIC, RADIOS AND TV'S ARE READILY AVAILABLE IN SCHOOLS AND CONVERT ELECTRICAL ENERGY TO SOUND (MECHANICAL ENERGY) AND LIGHT ENERGY. SMALL FLASHLIGHT LAMPS AND AUTO LAMPS ARE AVAILABLE LOCALLY AND CAN READILY BE EXPERIMENTED WITH, LIGHT EMITTING DIODES ARE AVAILABLE IN SEVERAL COLORS FOR PENNIES AT RADIO SHACK STORES AND SURPLUS HOUSES.

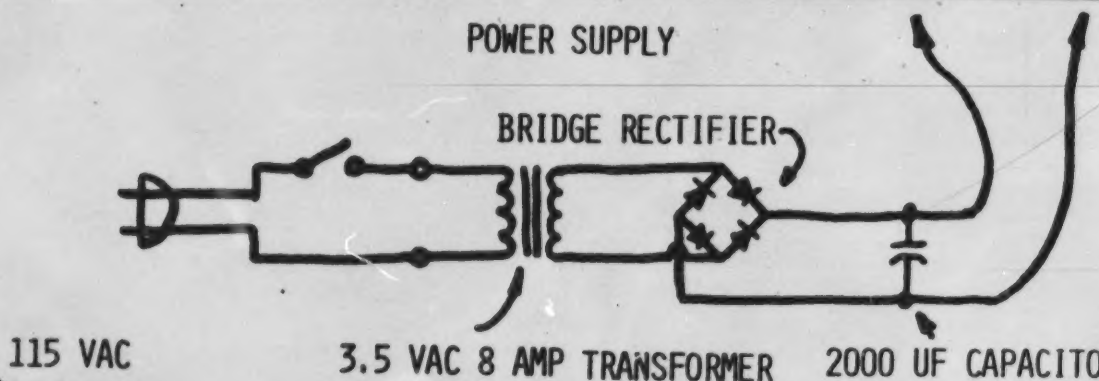
REFRIGERATOR SYSTEMS ARE LISTED AS A CONVERTER WITH ELECTRICAL ENERGY INPUT, WHICH THEY ARE. HOWEVER, THEY DO SO INDIRECTLY, THAT IS, THEY CONVERT ELECTRICAL ENERGY TO MECHANICAL ENERGY THROUGH A MOTOR, AND THEN THROUGH A COMPRESSOR TO HEAT ENERGY. AN INTERESTING DEVICE THAT HAS BECOME AVAILABLE IN RECENT YEARS BECAUSE OF LOW COST SEMI-CONDUCTORS CONVERTS ELECTRICAL ENERGY TO HEAT/COLD ENERGY. THE DEVICE IS CALLED AN ELECTRONIC COOLING MODULE OR PELTIER MODULE AFTER THE MAN WHO FIRST DISCOVERED THE EFFECT IN 1834. THE FIRST CONSUMER PRODUCT TO BECOME AVAILABLE USING THE PELTIER MODULE WAS THE INSULATED ICE CHEST OR POP COOLER DESIGNED TO OPERATE FROM A 12 V SOURCE, THUS IT IS IDEAL FOR CAMPERS ETC. LIKE THE PIEZOELECTRIC EFFECT, THE PELTIER EFFECT IS REVERSIBLE, THAT IS, HEAT WILL PRODUCE ELECTRICAL


THE SEEBECK AND PELTIER EFFECTS
IRON +
CONSTANTAN -
LOWER WORK FUNCTION MATERIAL
HIGHER WORK FUNCTION MATERIAL
+
-
CURRENT FLOW RESULTS FROM DIFFERENCE PRODUCED
+
METER
-
ELECTRONS
HOLES
N TYPE
P TYPE
(A)
N-TYPE
P-TYPE
(B)
E
E
(C)
HEAT

VISUAL # 9

A ONE-CAN ELECTRONIC POP COOLER


ONE INCH OF SPRAY FOAM INSULATION
LARGE TIN CAN
SMALL CAN - SLIGHTLY LARGER THAN POP CAN
ELECTRONIC COOLING (PELTIER) MODULE
SILICONE HEAT-CONDUCTIVE GREASE
LARGE ALUMINUM HEAT SINK



ENERGY. THIS EFFECT IS KNOWN AS THE SEEBECK EFFECT AND PRACTICAL DEVICES BASED ON THE EFFECT ARE CALLED THERMOCOUPLES. FOR CONVENIENCE BOTH EFFECTS WILL BE DISCUSSED HERE, ALTHOUGH THE SEEBECK EFFECT WILL BE DISCUSSED FURTHER IN THE APPROPRIATE TOPIC, 4.60 THERMAL ENERGY INPUT.

REFER TO THE TOP OF VISUAL #8. THE SEEBECK EFFECT CAN BE OBSERVED WITH ANY TWO DISSIMILIAR METALS. A SIMPLE DEMONSTRATION CAN BE PERFORMED IN THE LAB BY TWISTING A BARE COPPER AND IRON WIRE TOGETHER FOR APPROXIMATELY ONE INCH OF A TWELVE INCH LENGTH. HOOK A MULTI METER ON TO THE FREE ENDS (SET METER ON THE MOST SENSITIVE VOLTAGE OR CURRENT SCALE) AN LIGHT A PROPANE TORCH UNDER THE TWISTED ENDS. THE FEW MILLIVOLTS THAT ARE PRODUCED ARE A RESULT OF THE ACTION SHOWN. SOME METALS HAVE WHAT IS CALLED A LOW WORK FUNCTION, THAT IS THEY GIVE UP ELECTRONS WHEN ONLY A LITTLE HEAT OR ENERGY IS APPLIED. THESE FREE ELECTRONS MOVE TOWARD THE METAL THAT HAS A HIGHER WORK FUNCTION. THE AMOUNT OF VOLTAGE PRODUCED IS GREATEST WHEN THE DIFFERENCE BETWEEN THE WORK FUNCTION OF THE METALS USED IS GREATEST. SOME POPULAR COMBINATIONS ARE: IRON CONSTANTIN .03 V PER DEGREE F., CHROMEL-ALUMEL .023 V PER DEGREE F., COPPER-CONSTANTIN .025 V PER DEGREE F. BECAUSE THEY CAN WITHSTAND HIGH TEMPERATURES THEY ARE OFTEN USED TO MEASURE HIGH TEMPERATURES OF MOLTEN METALS. HIGH TEMPERATURE THERMOMETERS ARE CALLED PYROMETERS. THERMOCOUPLES MADE FROM DISSIMILIAR METALS ARE EXTREMELY INEFFICIENT AT ENERGY CONVERSION - TYPICAL EFFICIENCIES ARE LESS THAN 1%. AS A RESULT THEY ARE ALMOST TOTALLY USELESS WHEN USED AS A PELTIER MODULE TO REFRIGERATE MATERIALS.

SEMICONDUCTORS ARE MADE FROM CYRSTALLINE BLOCKS OF TWO DIFFERENT TYPES, ONE IS CALLED N MATERIAL WHICH HAS EXCESS FREE ELECTRONS AVAILABLE THROUGHOUT THE CRYSTAL AT ROOM TEMPERATURE. THE OTHER TYPE IS CALLED P MATERIAL WHICH HAS EXCESS VACANCIES FOR ELECTRONS IN THE OUTER SHELL OF THE ATOMS CALLED "HOLES". REFER TO DIAGRAM A IN VISUAL #8. IN DIAGRAM B THE TWO BLOCKS ARE JOINED AT ROOM TEMPERATURE BUT NO VOLTAGE IS PRODUCED. IN DIAGRAM C THE JUNCTION IS HEATED AND THE ELECTRONS AND HOLES, BOTH CURRENT CARRIERS MOVE AWAY FROM THE JUNCTION PRODUCING AN EXTERNAL VOLTAGE. THIS ACTION IS MUCH MUCH MORE EFFICIENT THAN THE DISSIMILIAR TYPE BUT BECAUSE IT CANNOT STAND HIGH TEMPERATURES THE SEMICONDUCTOR THERMOCOUPLE IS NOT USED AS A PYROMETER. HOWEVER, WHEN CURRENT IS APPLIED TO THE MATERIALS ONE SIDE GETS HOT AND THE OTHER GETS COLD. IF HEAT IS DRIANED AWAY FROM THE HOT SIDE QUICKLY BY A LARGE BLOCK OF ALUMINUM, THE COLD SIDE GETS EXTREMELY COLD, COLD ENOUGH TO FREEZE WATER IN A FEW MINUTES. MODULES OF THIS TYPE ARE AVAILABLE FROM LESS THAN $20 TO OVER $100 DEPENDING ON COOLING CAPACITY. IT IS MODULES OF THIS TYPE THAT ARE USED IN COMERCIALLY AVAILABLE ICE CHESTS ADVERTISED IN POPULAR MAGAZINES. THEY ARE AVAILABLE FROM HERBACH & RADEMAN (SEE APPENDIX) OR WRITE THE MANUFACTURERS: JERMYN, 712 MONTGOMERY STREET, SAN FRANCISCO, CA. 94111., CAMBRIRIDGE THERMONIC CORPORATION, 445 CONCORD AVE., CAMBRIDGE MASS 02138. HERBACH & RADEMAN CATALOG # 05308.

REFER TO VISUAL #9 FOR A LAB CONSTRUCTED ONE-CAN POP COOLER, AND THE POWER SUPPLY NECESSARY TO OPERATE IT FROM 120 VAC, IT CAN ALSO BE OPERATED FROM A 6V CAR BATTERY IF A .3-.4 OHM 20 WATT RESISTOR IS INSERTED IN SERIES. THE RESISTOR CAN BE MADE FROM NICHROME WIRE SALVAGED FROM A HAIR DRIER, HEATING ELEMENT, OR AUTO IGNITION BALLAST RESISTOR WIRE.

CURRICULUM GUIDE OUTLINE:

4.50 NUCLEAR ENERGY INPUT
- 4.51 NUCLEAR REACTORS
- 4.52 RADIOACTIVE ISOTOPES
- 4.53 X-RAYS
- 4.54 NUCLEAR BATTERY

FOR A DISCUSSION OF NUCLEAR CONVERTERS, REFER BACK TO FACT SHEETS 12, 13 14 AND VISUALS # 3 - 6, 3 - 7.

UNFORTUNATELY IT IS IMPRACTICAL TO EXPERIMENT IN A SIGNIFICANT WAY IN THE LAB WITH ANY NUCLEAR CONVERTER. HOWEVER, THERE ARE MANY DEVICES IN COMMON USE WHICH HARNESS NUCLEAR ENERGY FOR MANS BENEFIT.

A FEW ARE SHOWN IN VISUAL #10. INCLUDED ARE MEDICAL USES, X-RAYS, RADIATION TREATMENTS, FIRE AND SMOKE ALARMS WHICH HAVE A SMALL RADIOACTIVE ELEMENT IN THE SENSING DEVICE, DIGITAL WATCHES, SOME OF WHICH HAVE A TRACE OF RADIOACTIVE MATERIAL IN THE LIQUID CRYSTAL DISPLAY TO MAKE IT VISIBLE AFTER DARK, AND STATIC ELIMINATORS OFTEN USED IN DARKROOMS TO REMOVE DUST FROM NEGATIVES CONTAIN A RADIOACTIVE POLONIUM CARTRIDGE. THE STATIC ELIMINATORS ARE ARE AVAILABLE FROM MOST GRAPHIC ARTS AND PHOTO SUPPLY HOUSES UNDER THE TRADE NAME "STATIC MASTER". SO, IT IS INDEED POSSIBLE TO ASSEMBLE A NUMBER OF DEVICES WHICH ILLUSTRATE IN THE CLASSROOM THE USEFULNESS OF NUCLEAR ENERGY.

CURRICULUM GUIDE OUTLINE:

4.60 THERMAL ENERGY INPUT
- 4.61 THERMOSTAT
- 4.62 THERMOCOUPLE (THERMOELECTRIC GENERATOR)
- 4.63 THERMIONIC DEVICE
- 4.64 BOILING (WATER/STEAM)
- 4.65 HEAT RADIATION
- 4.66 THERMOVOLTAIC CONVERTER (TPV) (SOLAR DWELLING)

THE THERMOSTAT LISTED ABOVE CAN BE USED AS AN INTERESTING CLASSROOM ACTIVITY. SEE SCIENCE ACTIVITIES IN ENERGY (ATTACHED) FOR MORE IDEAS. THE PACKET WITH EXPERIMENTS ON HEAT INPUT DEVICES AND THERMOSTATS IS THE ONE ON CONSERVATION.

THE THERMOCOUPLE DISCUSSED IN THE PREVIOUS TOPIC 4.40 IS AN INTERESTING DEVICE THAT IS EASY TO EXPERIMENT WITH BECAUSE THE DEVICE ITSELF IS AVAILABLE AS A REPAIR ITEM IN LOCAL HARDWARE STORES. THE THERMOCOUPLE IS THE MAIN CONTROL ELEMENT IN MOST WATER HEATERS AND SOME OTHER APPLIANCES. BY HOOKING THE LEADS UP TO A MULTIMETER, PREFERABLY THE MOST SENSITIVE VOLTAGE SCALE, A CRUDE PYROMETER CAN BE MADE. IF ONE DESIRES TO MAKE A USEABE DEVICE SUCH AS ONE MIGHT USE FOR MEASURING THE TEMPERATURE OF MOLTEN ALUMINUM, THE THERMOCOUPLE CAN BE ATTACHED TO A THREE FOOT STEEL ROD WITH A WOODEN HANDLE. THE METER MOVEMENT CAN BE PURCHASED FROM LOCAL RADIO SHACK STORES FOR $7.95. IT HAS A SENSITIVITY OF 50 MICRO AMPS, .075 VOLTS, AND A RESISTANCE OF ABOUT 1500 OHMS. WHEN ATTACHED TO THE METER, MOST SINGLE ELEMENT THERMOCOUPLES WILL PROVIDE A 1/3 TO 1/2 SCALE DEFLECTION WHEN THE HEAT OF A PROPANE TORCH IS APPLIED TO THE TIP. THIS TEMPERATURE IS MUCH GREATER THAN MOLTEN ALUMINUM, SO ONE MAY WISH TO WIRE TWO OR THREE ELEMENTS IN SERIES TO OBTAIN A SIZEABLE NEEDLE MOVEMENT. TO CALIBRATE THE PYROMETER, THE

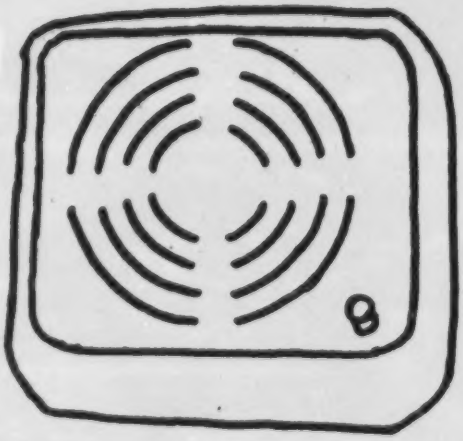
10

VISUAL #

MEDICAL TRACER ELEMENTS AND
X - RAYS

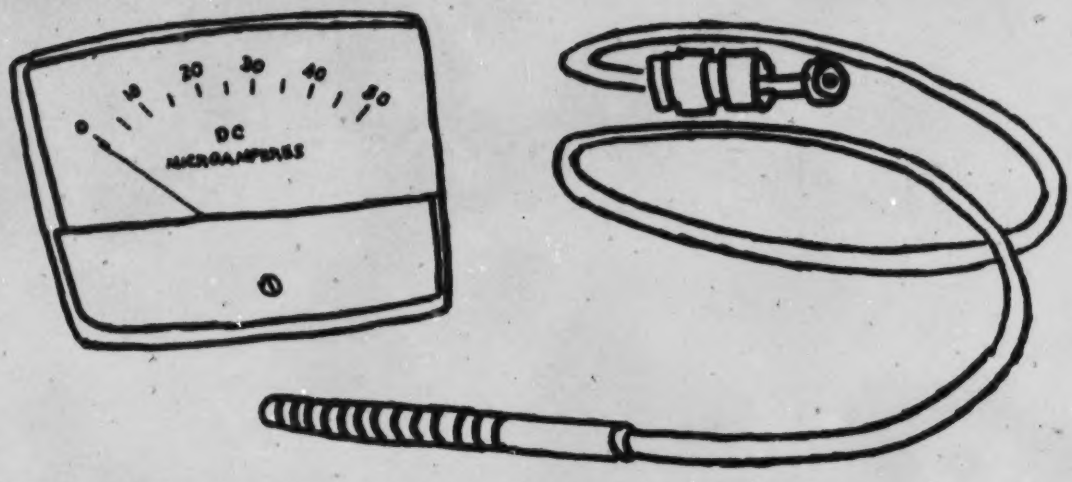
RADIOACTIVE
LIQUID CRYSTAL
DISPLAYS

RADIOACTIVE MATERIAL IN SENSOR
ELEMENT OF SMOKE & FIRE ALARM

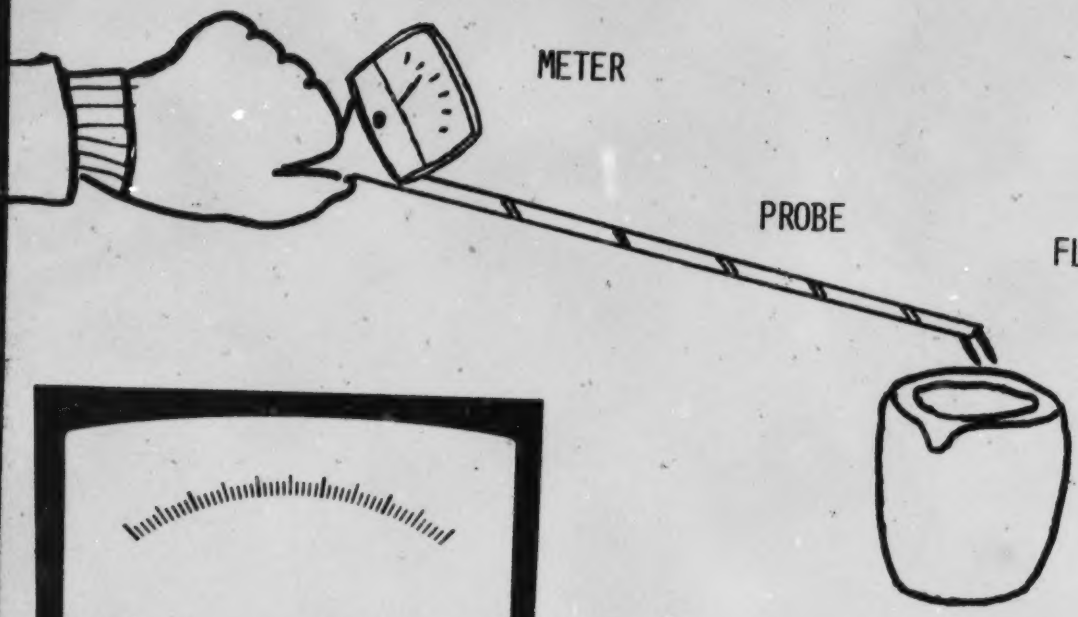


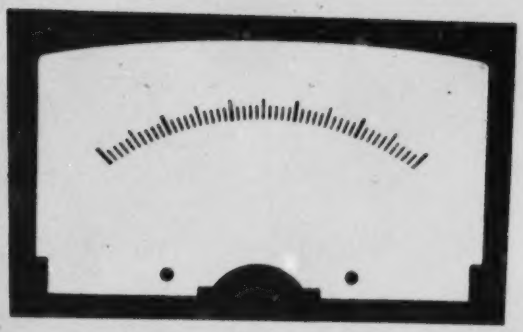
RADIOACTIVE POLONIUM CARTRIDGE
REMOVES STATIC ELECTRICITY
& DUST FROM NEGATIVES

VISUAL # 11



50 MICRO_-AMP METER MOVEMENT WATER HEATER THERMOCOUPLE ELEMENT

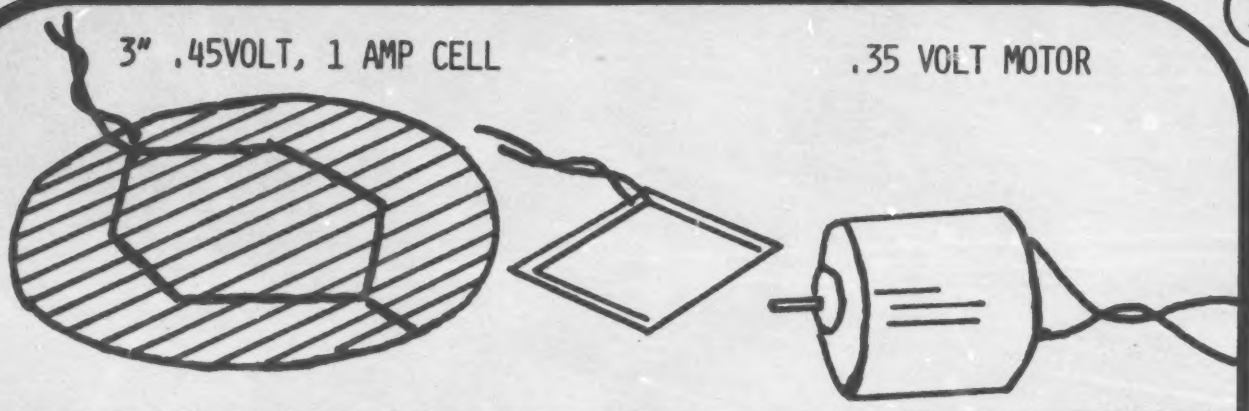


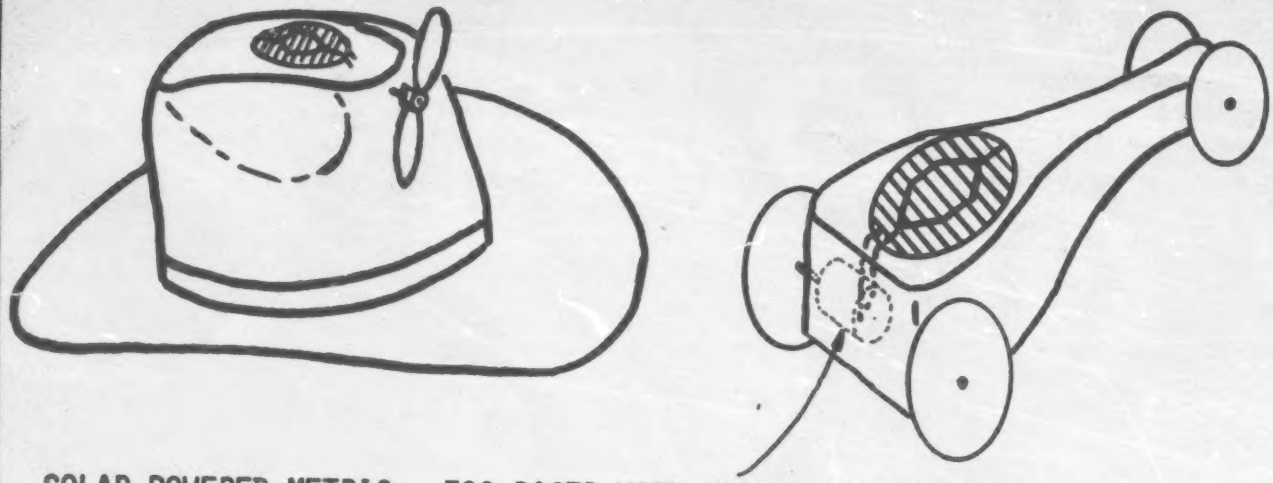


BLANK METER FACE FOR RECALIBRATION

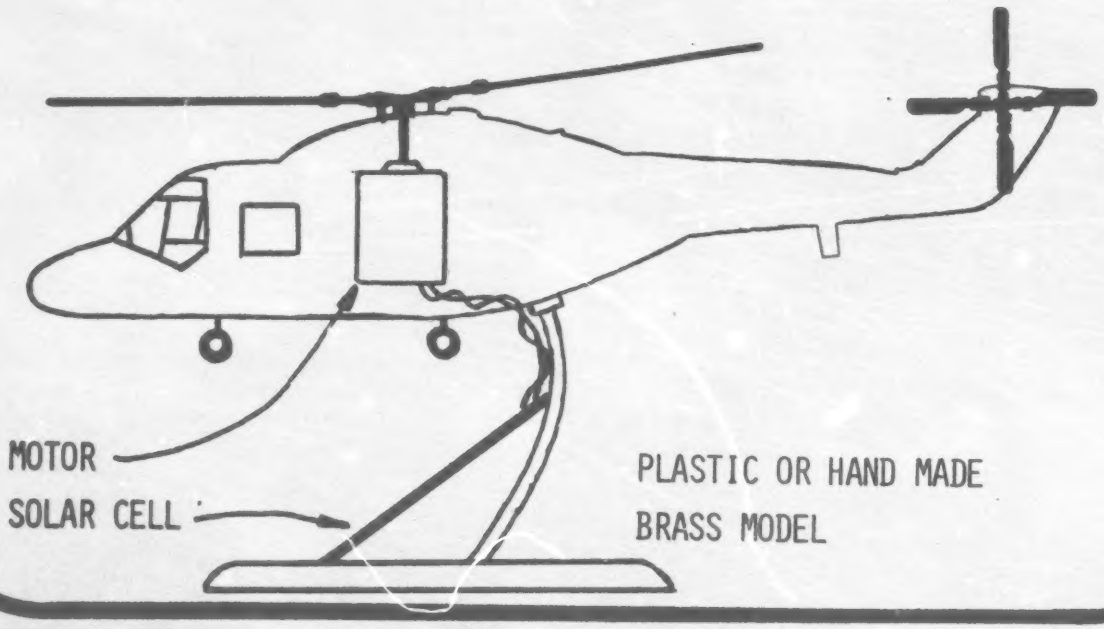
12

VISUAL #





SOLAR POWERED METRIC - 500 RACER WITH DIRECT MOUNTED MOTOR



unit 5
energy/power storage, transmission and control

LECTURE NOTES

THE MERE CONVERSION OF ENERGY FROM ONE FORM TO ANOTHER IS SELDOM SUFFICIENT TO MEET MANS NEEDS. FOR EXAMPLE, WE CAN EASILY CONVERT THE SUNS ENERGY TO ELECTRICITY, WHICH IS A READILY USEABLE FORM. HOWEVER, THE TOTAL NUMBER OF SUNNY DAYS IN A GIVEN LOCAL MAY BE SMALL, ALSO WE MOST NEED ELECTRICITY FOR LIGHTING AFTER THE SUN GOES DOWN. ANOTHER EXAMPLE OF THE INADEQUACY OF SIMPLE CONVERSION IS THE WIND GENERATOR, WHICH BY ITSELF IS VERY LIMITED IN USEFULLNESS. WE MUST FIRST FIND A SUITABLE MEANS OF STORAGE FOR PERIODS WHEN THE CONVERTER CANNOT OPERATE, THEN MOST LIKELY WE WILL NEED TO TRANSPORT THE ENERGY TO WHERE IT IS MOST NEEDED, AND SOMEHOW REGULATE THE FLOW OR CONTROL THE ENERGY USEAGE FOR MAXIMUM EFFICIENCY AND SAFETY. UNIT #5 IN THE CURRICULUM GUIDE COVERS THESE THREE ELEMENTS: STORAGE, TRANSMISSION AND CONTROL.

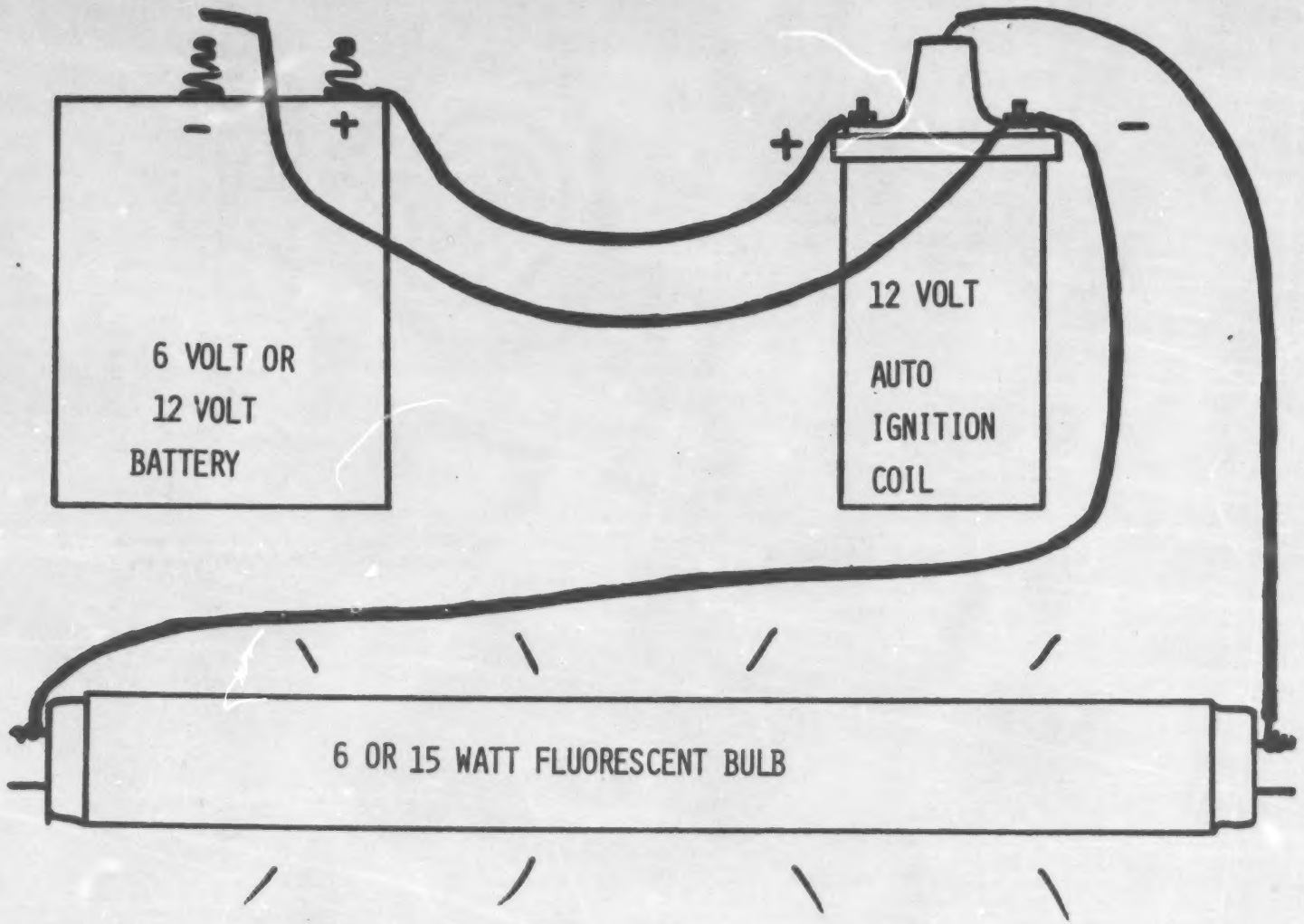
CURRICULUM GUIDE OUTLINE:

5.00 ENERGY/POWER STORAGE, TRANSMISSION AND CONTROL
- 5.10 STORAGE OF ENERGY
  - 5.11 MOMENTARY
    - 5.111 IGNITION COIL
    - 5.112 CAPACITOR
    - 5.113 METAL SPRING
    - 5.114 ETC.
  - 5.12 TEMPORARY
    - 5.121 BATTERY
    - 5.122 DAM
    - 5.123 HEAT STORAGE TANK
    - 5.124 SHIELDED NUCLEAR STORAGE DEVICE
    - 5.125 ETC.

FOR A DISCUSSION OF ENERGY STORAGE TECHNOLOGY, REFER TO FACT SHEET #16 ON THE FOLLOWING PAGES. ONE OF THE EASIEST WAYS TO DEMONSTRATE THE MOMENTARY STORAGE OF ENERGY IN THE CLASSROOM IS BY USE OF AN AUTO IGNITION COIL, 6 OR 12 VOLT BATTERY, AND A 15W FLUORESCENT BULB. HOOK UP THE PARTS AS SHOWN IN VISUAL #1.

WHEN THE WIRES ARE CONNECTED, CURRENT FLOWS FORCING THE ELECTRON SPINS TO ALIGN THEMSELVES PRODUCING AN EXTERNALLY DETECTABLE MAGNETIC FIELD. THIS "PUMPING" OF ENERGY INTO A MAGNETIC FIELD IS QUITE ANALOGOUS TO BLOWING UP A BALLOON. WHEN THE BALLOON IS RELEASED, THE ENERGY IS RETURNED. THE SAME IS TRUE OF THE FIELD, WHEN THE WIRE IS DISCONNECTED, THE FIELD COLLAPSES CUTTING THROUGH THE COIL WIRE PRODUCING A CURRENT MUCH AS A GENERATOR DOES. WHILE THIS ACTION IS AT PRESENT ONLY MOMENTARY, IT IS EXTREMELY IMPORTANT, WITHOUT IT, THE ELECTRIC WORLD AS WE KNOW IT WOULD NOT EXIST. IN THE FUTURE IT MAY BECOME EVEN MORE IMPORTANT FOR LONG TERM STORAGE AS SUPERCONDUCTORS BECOME MORE PRACTICAL. SEE FACT SHEET #16 FOR MORE INFORMATION.

NOTE THAT THE BULB FLASHES MOMENTARILY ONLY WHEN THE WIRE IS DISCONNECTED. IF FLASH IS NOT VISIBLE, IT MAY BE THAT THE ROOM LIGHT IS TOO INTENSE. IF FLASH STILL IS NOT VISIBLE IN A DARKENED ROOM, TRY USING A SMALL NEON LAMP OF THE TYPE FOUND IN 120 VAC TEST LAMPS AVAILABLE IN MOST HARDWARE STORES, OR SIMPLY USE A SPARK PLUG.



168 DEMONSTRATING MOMENTARY ENERGY STORAGE BY A MAGNETIC FIELD 169

VISUAL # 1

FACTSHEET

National Science Teachers Association

16. ENERGY STORAGE TECHNOLOGY

John M. Fowler

INTRODUCTION

The common image of energy emphasizes its flow - through an industrial society, an ecosystem, or the like. Energy is extracted from some source, converted to useful forms, and eventually flows out the other end, unchanged in amounts, but degraded in usefulness. Looking more closely at this dynamic picture, however, we discover static periods when energy does not flow, when it is stored. In fact, since the consuming system - industrial or biological - does not always need energy at a uniform rate, the ability to store it is most important. A factory stockpiles coal, a squirrel stockpiles nuts.

The great usefulness of the fossil fuels - coal, oil, and natural gas - comes from the large amounts of energy per pound stored in them. We rely, in fact, completely on stored forms. 96 percent of the total U.S. consumption comes from fossil fuels and the remainder is divided between the stored gravitational energy of water and energy stored in the atomic nucleus.

The weakness of relying on the fossil fuels is becoming obvious. The conversion process is almost always combustion and we pay penalties of inefficiency and environmental harm for so much burning. The fuels, with the most efficient storage - oil and natural gas - are now becoming scarce.

The fossil fuels were an energy bonanza, and on them human kind built a society which uses (worldwide) 270 Q Btu* of energy per year (1974 data). To replace them, equally large sources will be needed and the only present candidates are solar energy (see Fact Sheet 1,2,3,4,5,6,7), fusion energy (Fact Sheet #14) or the fission-powered, breeder reactor (Fact Sheet #13). For all of these sources, storage will be crucial; for solar energy because it is erratic, and for the others because they produce electricity which must be either used or stored as soon as it is generated.

This is the grand view of the necessity for energy storage. The large sources turn out energy at a steady rate (the sun for natural reasons and the two nuclear sources for reasons of efficiency and engineering necessity). To match them to human needs, some of their abundance must be banked for hard times.

In this Fact Sheet, we will describe the advantages that improved means of energy storage could bring and examine the various new storage technologies that are being investigated.

RESOURCES AND APPLICATIONS

Two kinds of energy resources can be opened up by new storage technology. The large one is, of course, solar energy, which floods the earth each year with 18,000 times as much energy as man uses. We have so far, only tapped that minuscle fraction stored millions of years ago in the fossil

* A quad (quadrillion), abbreviated Q is 10^{15}. Units of energy (Btu) are defined in the Glossary, Fact Sheet #18.

1977

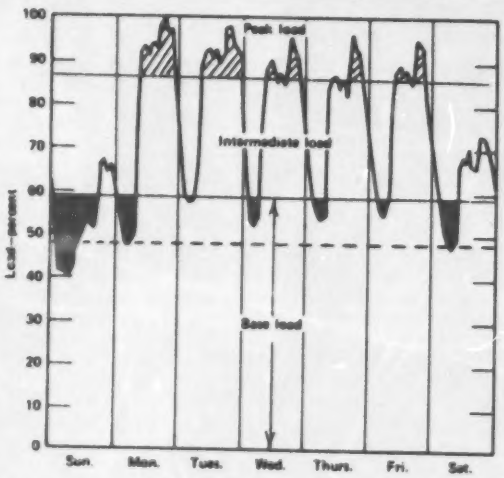
This material was produced by the National Science Teachers Association under contract with the U.S. Energy Research and Development Administration. The facts, statistics projections, and conclusions are those of the authors.

fuels, along with some of the solar energy stored in water, when it is evaporated and lifted to the rain clouds. If we are to use direct solar energy, we must not only convert it to something we need (electricity or heat energy, for instance) but also store it against those inevitable times when the sun does not shine.

The other resource is a "conservation resource"; energy released for other uses when conversion or utilization efficiency is improved. The most urgent need for storage of this kind is in the electrical sector. Electricity, as we have said, must be used as soon as it is produced, but electrical demand varies on an hourly, daily, weekly, and seasonal basis. The most efficient generators, the large fossil fuel-fired or nuclear plants, do not, however, have variable outputs. They are used for the so-called "baseload generation" which provides for the relatively constant part of the overall demand. This means that the variable demand must be met by turning on a series of less efficient diesel or natural gas-fired generators.

The typical weekly "load curve" of an electric utility is shown in the illustration below:

Typical Power Plant Weekly Load Curve



● Baseload Energy to Storage

▨ Peaking Energy from Storage

– – – – – – – – Original Baseload

As one can see, the peaks and valleys represent load changes of 30 to 40 percent. If the baseload generators could produce electricity for storage, and thus continue to run (and fill in the valleys as shown) this electricity would then be available to meet some of the peak demand. What this would accomplish, in fact, is to replace inefficient generators or "spinning reserve" (hydroelectric or steam powered turbines, which are actually turning although not generating electricity) by the more efficient baseload storage system. It is obvious that very efficient storage will be needed, since the savings depend on recovering the difference between the 40 percent efficiency of baseload generation and the 25 to 30 percent efficiency of peak or intermediate load generation. It is also clear from the illustration that the storage cycle will have to cover a week since most of the off-peak energy is available on weekends.

With a weekly cycle and an efficiency of 75 percent, storage could replace almost 10 percent of the total utility generating capacity, saving both money and fuel. Several of the technologies we will discuss below are designed for this purpose.

Large scale electrical storage techniques will be necessary if and when the new electrical generating systems based on fission or fusion come into being, for these installations will also be used for baseload power. Storage will, in fact, be necessary for fusion reactors as they are now envisioned. As discussed in Fact Sheet #14, large amounts of energy will be needed for the magnetic fields, heat systems, lasers, etc., and this energy will in all likelihood be most economically supplied by the reactor itself, and then stored for the next cycle.

The other two applications of storage technology which would improve energy utilization efficiency are 1) a mobile source of electrical energy for transportation and 2) an inexpensive means for transporting and storing heat energy. Success in this latter effort would not only allow homes and buildings to be heated by excess heat from electric power plants, but also would make solar heating practical. Thermal storage in buildings would also be useful in connection with heat pumps. Off-peak electricity could be used to store thermal energy in the heat pump reservoir for use as needed. This process could be reversed in the summer and the reservoir cooled by the heat pumps, thus reducing the daytime air conditioning load.

In certain industries, in which things are always being heated, cooled, and reheated, thermal storage could also improve energy utilization efficiency.

We will describe below the several new thrusts of technology toward the satisfaction of these needs.

TECHNOLOGY

A large variety of purposes could be served

by versatile energy storage techniques. There are a correspondingly large variety of storage techniques under development. We will discuss them by categories, considering together those techniques which store energy in a mechanical form, in thermal form, and in chemical form.

Mechanical Storage

The flywheel, a massive wheel which stores rotational kinetic energy, has long been used to smooth out the power available from one or two cycle engines and adjust for uneven loads. The new uses of this device, and of the other two mechanical storage techniques to be discussed, take advantage of the reversibility of the electric motor/generator. With proper design, an electric engine can be run as a motor with an input of electric power or as a generator with an input of mechanical power.

Flywheel storage is being tested both for transportation and for use in electric utility systems. It has been tested for energy storage in buses. An electric motor energizes the flywheel and the bus runs on this energy for a few miles between recharging stations. The most important use will probably be regenerative braking. A subway train, for instance, may use a flywheel to slow down (by transferring energy to it from the wheels) and then reuse this energy for acceleration. In such stop and start operations, energy savings as high as 30 percent may be realized (and the subway tunnels will be more comfortable without the heat dissipated by friction braking). In utilities, a large flywheel located near a point of electric power demand could be set spinning by a motor using off-peak power and then drive the motor as a generator when additional electricity is needed.

Although flywheels offer 80-90 percent efficiency, much more research and development (new materials, new shapes) is needed to make them practical for large scale storage.

Pumped storage is already in use; there were about 8000 Mw of generating capacity of this type in existence in 1974 and 40,000 Mw are projected in 1990.

In pumped storage, reversible pump/turbines pump water uphill into a storage reservoir and can then operate as turbines, turning generators, when the water runs back down through them. It is a relatively efficient technique, only about one third of the energy is lost during the turn around (67% efficiency), but it has often run into violent environmental opposition. The controversy over such use for Storm King Mountain on the Hudson, for instance, still continues. Underground pumped storage is being investigated as an answer to environmental objections. Pumped storage has proven itself economically viable, but its eventual use is limited by geography to only a few percent of the hydroelectric total.

Compressed air can be used to store energy. This technique also takes advantage of off-peak electrical generating capacity and is intended to accompany gas turbines in the same way that pumped storage accompanied water turbines. The technique, in brief, is the following. For a gas turbine to operate properly, compressed, hot air must be supplied. About two-thirds of the energy needed to run a gas turbine is used by the compressor.

It is proposed to decouple the compressor and the turbine, run the former during off-peak times to produce compressed air, then store it in natural caverns, old oil or gas wells, or porous rock formations. It is also suggested that the heat generated when the air is compressed be stored and used to preheat the air, thus adding to the efficiency.

The technique is sound from an engineering point of view, the remaining questions are geophysical: Can airtight storage areas be found? How high will the losses be? Will the air be contaminated and damage the turbine?

Thermal Storage

Heat energy is the universal waste product - the end of the downhill run of energy described by the second law of thermodynamics. This heat energy would be useful, however, to warm buildings and drive industrial processes. Heat energy accounts for more than half our energy consumption.

The domestic water heater stores low temperature energy and in Europe ceramic bricks have been used to store energy for home heating. The energy is variously provided by fireplaces, stoves, or in a very successful West German load-leveling experiment, by electric heaters which heat the bricks with off-peak power. The German utility company which pioneered the idea is now oversubscribed and will only install new heaters as their overall demand increases.

Thermal storage in connection with electrical space heating has not been attractive in this country. Not only have energy cuts been low but also, most utility systems have been experiencing a summer peak and so there has been idle capacity in the winter. If electric space heating continues to grow this situation will change. Each new air condi-

tioning customer adds 2½ to 3 kw to the demand while each new space heating cutomer adds 10 to 12 kw to the peak load.

It is expected that much of the new heating load will be provided by heat pumps. These devices are much more efficient than resistance heaters but they are most efficient when they operate over a relatively small temperature difference. For this reason a solar collecting system providing heat to a reservoir which serves as a source to a heat pump may prove to be a good combination. It may even prove economical to heat a reservoir with off-peak electricity.

Storage will, of course, be crucial for solar heating and it is being assumed that it will be economically important to have, at least, 2 to 3 days of capacity. Water tanks or rock bins are now in use and the search is on for other techniques.

There is also much interest in storing "coolness." Large overall gains in system efficiencies could be made if it were practical to cool water with off-peak electricity at night and use this to reduce air conditioning demand during the day. "Coolness," however, is even more difficult to store than heat.

A seasonal storage approach being developed at Oak Ridge (the ACES system described briefly in Fact Sheet #7) has had some success. A large insulated tank of water is used as a source of heat for a heat pump in the winter and the nearly frozen water reservoir is then used for summertime cooling. This interesting new idea is undergoing testing and economic analysis.

Experience is meager with storing the high temperature heat - steam, for instance - which is needed in many industrial processes and in the generation of electricity.

If, however, solar thermal technologies are to be successful (see Fact Sheet #5), storage of high temperature heat for 2 to 3 days will be necessary. New inexpensive and highly effective insulation materials and/or materials with very high capacities must be developed.

Chemical Storage

Chemical storage has many advantages over mechanical or thermal storage. It is a very stable storage technique and provides the high energy density needed for transportation (which the gasoline tank provides, for instance). Much of the new research and development effort, therefore, focuses on chemical systems.

Batteries are well known and successful storage devices. In the lead-acid automobile storage battery, a lead compound at one electrode interacts with the sulphuric acid solution (the electrolyte) which fills each cell. Electrons are released, flow through the circuit and provide the electric power. In the process both the lead compound and the sulphuric acid are changed. The battery can be recharged by forcing electric current through it (forcing electrons to flow back in the other direction). This restores both the electrodes and the sulphuric acid at an energy conversion efficiency of about 80 percent.

These batteries are too heavy for vehicular use. To obtain reasonable automobile operation - 100 miles of range and 0-10 MPH in 10 second acceleration - takes energy and power storage capacity of 90 watt-hours and 60 watts per pound. Lead acid batteries produce only 16-20 watt-hours and 35 watts per pound. Experimentation with lighter weight electrodes (grids or meshes) may reduce both the weight and cost of lead batteries.

Among the most interesting new ideas are the molten salt batteries whose electrodes are molten sodium, Na, and sulphur, S, separated by a solid electrolyte (a ceramic material which allows the sodium atoms to pass). These NaS batteries have energy densities greater than 220 watt-hours per pound (and comparable power densities). Another significant advantage is their ability to undergo many charge-discharge cycles. Duty cycles of 2000 to 3000 may be possible (and necessary). Since the electrodes are liquid, there is no geometric (or other) structure which needs to be reproduced.

Their chief disadvantage is that they must be maintained at a temperature between 250 and 330° C, an added complication for vehicle batteries. Present plans call for the batteries to be very well insulated and it is expected that they will be able to store for several days the heat energy given off when they are charged.

The design of batteries to store utility-generated electricity is also a program of major importance. The contender here is a battery with a molten lithium and a solid iron sulfide electrode. It requires high temperature operation, but since these batteries are to be used in stationary banks to store off-peak power, this condition is easier to achieve than in the case of vehicles. Such batteries could also store electricity generated by solar, wind, and other new sources.

Fuel Cells are very much like batteries, but

with the important difference that the components which react to produce the electric current are continuously fed in and the reaction products are removed. A fuel cell, therefore, is a continuous source of electric power and does not need recharging like a battery.

The ideal fuel for a fuel cell is hydrogen with oxygen supplied at the other electrode. When hydrogen and oxygen come together, electrons leave the hydrogen and attach to the oxygen and energy is released. This usually happens explosively, the hydrogen burns. In the fuel cell, the two atoms are kept apart and the electrons flow around a circuit from the hydrogen electrode to the oxygen one. The stored chemical energy is released as electrical energy. The "waste product" of the combination of hydrogen and oxygen is water, H_2O, an environmentally acceptable exhaust.

Fuel cells have been used successfully on space vehicles. Their present development takes two directions. Relatively small (40 kw) fuel cells operating on natural gas (which is the source of hydrogen) are being tested for onsite generation of electricity at apartment complexes, schools, etc.

A second R & D effort is aimed at producing a larger, 26 Mw, unit to serve as a supplementary source within the normal utility distribution system. The fact that it is quiet, non-polluting and quickly assembled will make it, the utilities hope, a most useful addition to their system. They can be located in the city, for instance, and reduce the need for transmission lines and they take up little space. A 26 Mw unit would occupy less than an acre of land.

Fuel cells are quite efficient; even taking into account the loss incurred in producing hydrogen from natural gas they still have conversion efficiencies of about 40 percent. Since electrical energy is lost in transmission, a fuel cell of the same efficiency as a power plant would still produce more energy at the point of use, per unit of fuel converted, than the conventional plant.

It is the ability to produce electricity from natural gas on demand that qualifies the fuel cell for discussion in this Fact Sheet on energy storage. An even more interesting, but more visionary possibility, is that the fuel cell may become an important part of a future hydrogen-based energy system.

Hydrogen can be produced by electrolysing water into its two components, hydrogen and oxygen. It takes energy to accomplish this, of course, but much of that energy can be recovered when the hydrogen and oxygen are recombined.

Hydrogen could be a versatile intermediate form of energy. Its transporation by underground pipe should, it appears, be easier and cheaper than electrical transmission. It could be converted at the point of use to produce electricity in a fuel cell, is light enough to be used in automobiles and airplanes, and would fill the other needs which presently demand natural gas. It also has a variety of industrial possibilities from iron making to coal gasification and liquefaction (see Fact Sheet #15).

The vision seen by its enthusiasts is of hydrogen production from water at large (solar, fusion, breeder, etc.) electrical generating plants. The two major barriers to be surmounted are the cost of electrolysis and the difficulty of hydrogen storage.

Energy stored by electrolysis will be tied to the cost of electricity. An important search is on, therefore, to find other ways to separate hydrogen and oxygen from water. It can be done at temperatures of 2500° C (and some solar plants may provide that) but it will be more practical if a chain of reactions can be found that allow efficient production at the temperatures of 700-1000° C found in nuclear reactors or fossil fuel plants.

Storage of hydrogen is a problem because it is so light and therefore occupies a lot of space. Its liquefaction requires extremely low temperatures (below that of liquid air) but it may be used as a liquid for air travel. For automobiles, hydrogen absorption in granulated metal - from which it can be extracted by heating, may be the answer.

Even though its use is far from practical at present, hydrogen offers an attractive alternate future to electrification of the country that the present directions of energy development are taking.

Magnetic storage of energy is an even more futuristic possibility. This technique would employ superconductors (materials which at very low temperatures, near absolute zero, have no electrical resistance and thus can store large amounts of electrical energy with no losses). Energy would be put into and taken out of the magnetic field around the superconducting ring by induction (by using it as a transformer). To be commercially practical, huge amounts of energy - 10,000 Mw hr or so - would have to be stored to compensate for the high cost of the facility. A 28 kw-hr experimental facility is being planned with construction to begin in 1978.

LECTURE NOTES

SUMMARY

At present, we have no effective competition to the fossil fuels for storing energy. Development of lightweight, efficient storage systems for transportation and large scale techniques for use in the electric utility system would significantly increase the efficiency with which we utilize energy. Storage will also be necessary if we are to use solar energy to get the most out of our breeder or fusion reactors. (It will be crucial to the operation of fusion reactors.)

Pumped storage is the only proven large scale technology. For the near term, underground pumped storage, compressed air storage, and thermal storage with a central advanced power plant appear to be the most feasible. For the long term (beyond 1985) the advanced batteries are promising and hydrogen may come into use in special situations. Beyond these technologies lies the possibility of magnetic storage and large scale use of hydrogen.

ERDA is fairly deeply engaged in the support of R & D for energy storage technology; with $23.0 million in its FY 1976 budget in this area and $31.0 million in FY 1977. Successful development will save energy, reduce environmental conflict, and ultimately, it is hoped open up new sources for exploitation. Like conservation, storage technology seems to promise more energy per dollar than those techniques which depend on exotic extraction or conversion methods.

REFERENCES

1. "Energy Storage" F.R. Kalhammer and Thomas R. Schneider, pp. 311-344 in Annual Reviews of Energy, Vol. 1, J. Hallander and M. Simmons, editors (Palo Alto, Calif.: Annual Reviews Inc.) 1976.

2. "Storing Electricity," R. Whitaker, pp. 16-20, 38-39, Environment, 19 #2, March 1977.

3. "Energy Storage," Wm. Eaton, (Avaliable from: ERDA, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830) 1975.

4. "Criteria for Energy Storage R & D," Committee on Advanced Energy Storage Systems, National Academy of Sciences, (2101 Constitution Ave., N.W., Washington, D.C. 20418) 1976 (Stock # ISBN 0-309-02530-3, $6.25).

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from: ERDA-Technical Information Center P.O. Box 62, Oak Ridge, TN 37830

LECTURE NOTES

CURRICULUM GUIDE OUTLINE:

5.20 MEDIA OF TRANSMISSION

5.21 ELECTRICAL ENERGY

5.211 GAS OR VACUUM MEDIA

5.2111 ELECTROMAGNETIC WAVES

5.2112 LAMPS

5.2113 TUBES

5.2114 ETC.

5.212 SOLID MEDIA

5.2121 CONDUCTORS, WIRES, ETC.

5.2122 SEMICONDUCTORS, SOLID STATE, ETC

5.213 LIQUID MEDIA

5.2131 ELECTROPLATING

5.2132 IONIZATION

5.2133 ETC.

YOU WILL NOTE FROM THE CURRICULUM GUIDE OUTLINE THAT ELECTRICAL ENERGY, AND ALL OTHER FORMS OF ENERGY, ARE EXAMINED IN TERMS OF THE MEDIA IN WHICH OR THROUGH WHICH IT CAN BE TRANSMITTED. ELECTRICAL ENERGY, THERMAL ENERGY, AND LIGHT ENERGY ARE ALL ALIKE IN THAT THEY CAN EXIST IN THE FORM OF ELECTROMAGNETIC RADIATION WHICH WILL TRAVEL THROUGH SPACE AS WELL AS AIR OR A GAS, LIQUIDS, AND SOLIDS. REFER TO VISUAL #2 FOR AN ILLUSTRATION OF ELECTROMAGNETIC RADIATION SUCH AS THAT EMITTED FROM AN ANTENNA WIRE THROUGH WHICH AN ALTERNATING CURRENT IS FLOWING. BECAUSE THE ENERGY EMITTED FROM THE WIRE IS OF A FREQUENCY WHICH IS NOT ONE OF THOSE TO WHICH THE BODIES SENSES ARE SENSITIVE TO, IT SEEMS MYSTERIOUS. WHILE THE MATHEMATICS BEHIND THIS EMISSION PROCESS IS INDEED COMPLEX, ONE DOES NOT NEED TO UNDERSTAND IT FULLY TO UTILIZE IT OR FEEL COMFORTABLE WITH IT. ONE NEEDS ONLY THINK OF THE COMMON MATCH TO REALIZE THAT IT TOO IS A RADIO TRANSMITTER, THE FREQUENCIES IT RADIATES ARE ONES THAT THE EYE CAN SEE AND THE SKIN CAN FEEL. ONE CAN EASILY DEMONSTRATE A SIMPLE RADIO TRANSMITTER USING THE APPARATUS SHOWN IN VISUAL #1. SIMPLY PLACE A SMALL TRANSISTOR RADIO NEXT TO IT AND LISTEN TO THE STATIC PRODUCED BY THE SPARK. IF ONE KNOWS THE INTERNATIONAL MORSE CODE, MESSAGES CAN BE SENT WITH EQUIPMENT THIS SIMPLE, INDEED WIRELESS TELEGRAPHY IN USE AT THE TIME THE TITANIC SENT OUT ITS S.O.S. SIGNAL UTILIZED EQUIPMENT ONLY SLIGHTLY MORE SOPHISTICATED. THIS ENERGY RADIATED DOES NOT CONSIST OF ELECTRONS, BUT WHEN IT STRIKES ANOTHER ANTENNA WIRE, IT WILL FORCE A CURRENT TO FLOW IN IT EXACTLY LIKE THE CURRENT THAT IS FLOWING IN THE TRANSMITTING ANTENNA WIRE.

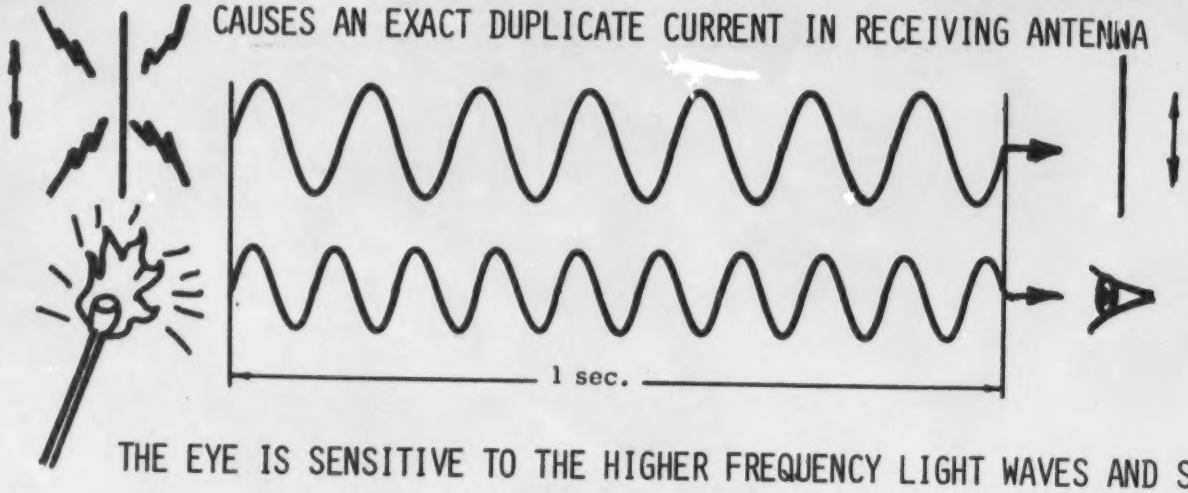
ELECTRICAL ENERGY ALSO FLOWS IN SOLID MATERIALS IN THE FORM OF MOVING ELECTRONS, AND IN THE CASE OF SEMICONDUCTORS, BOTH IN THE FORM OF POSITIVE CHARGES CALLED HOLES, AND ALSO ELECTRONS. THIS CAN BE DEMONSTRATED AS EASILY AS FLIPPING ON THE LIGHT SWITCH IN THE CLASSROOM AND IN HUNDREDS OF OTHER EQUALLY SIMPLE WAYS. CURRENT ALSO FLOWS IN LIQUIDS IN A MANNER SOMEWHAT SIMILIAR TO THAT OF THE SEMICONDUCTOR MATERIALS. THAT IS, CURRENT CONSISTS OF BOTH NEGATIVE CHARGES (ELECTRONS) AND POSITIVE CHARGES (POSITIVE IONS). THE MAJOR DIFFERENCE IS THAT THE DISASSOCIATION THAT OCCURS ALLOWS THE ENTIRE POSITIVE NUCLEUS TO MOVE TOWARD THE ELECTRODE JUST AS THE ELECTRONS MOVE IN THE OPPOSITE DIRECTION.

AN INTERESTING AND VERY SIMPLE WAY TO DEMONSTRATE THIS IS TO ELECTROPLATE A SMALL OBJECT. SEE THE "SCIENCE ACTIVITIES IN ENERGY" SERIES. THE EXERCISE IS DESCRIBED IN THE ELECTRICAL ENERGY PACKAGE.

2

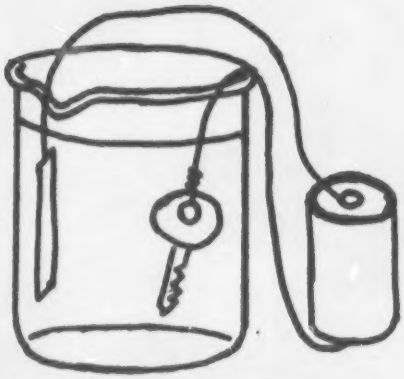
VISUAL #

HIGH FREQUENCY ALTERNATING CURRENT IN TRANSMITTING ANTENNA CAUSES AN EXACT DUPLICATE CURRENT IN RECEIVING ANTENNA



THE EYE IS SENSITIVE TO THE HIGHER FREQUENCY LIGHT WAVES AND SO ACTS AS AN ANTENNA. THE EYE IS NOT SENSITIVE TO THE LOWER FREQUENCY RADIO WAVE. BOTH TRAVEL 300,000 KM IN ONE SECOND

ELECTRICAL ENERGY TRAVELS THROUGH SOLIDS, LIQUIDS, AND GASES AS WELL AS THROUGH SPACE OR A VACUUM



CURRICULUM GUIDE OUTLINE:

5.22 LIGHT ENERGY
- 5.221 GAS OR VACUUM MEDIA
  - 5.2211 ELECTROMAGNETIC RADIATION
  - 5.2212 ETC.
- 5.222 SOLID MEDIA
  - 5.2221 TRANSPARENT MATERIALS (GLASS TRANSMISSION CABLE
  - 5.2222 TRANSLUCENT MATERIALS
- 5.223 LIQUID (CRYSTAL DISPLAY DEVICES)

OF ALL THE MEDIA THAT CAN TRANSMIT LIGHT ENERGY, THE ONE THAT PROMISES TO CHANGE OUR LIVES PERHAPS AS MUCH AS THE COMPUTER, IS THE FIBER-OPTIC CABLE. IT HAS EMERGED OVER THE LAST FEW YEARS AS THE ALMOST IDEAL WAY TO TRANSMIT INFORMATION - SO MUCH INFORMATION - THAT WE WILL SCARCELY HAVE TO STEP OUT OF OUR HOMES TO LIVE A FULL LIFE RICH IN EVERY TYPE OF EXPERIENCE. REFER TO VISUAL #3 FOR CLASS DISCUSSION. A WELL ILLUSTRATED AND WRITTEN EASILY OBTAINED REFERENCE ARTICLE CAN BE FOUND ON PP. 516, 535, NATIONAL GEOGRAPHIC MAGAZINE, OCTOBER, 1979.

EDMUND SCIENTIFIC (SEE APPENDIX) MARKETS INEXPENSIVE FIBER-OPTIC EXPERIMENTATION KITS FOR CLASSROOM USE.

CURRICULUM GUIDE OUTLINE:

5.23 THERMAL ENERGY
- 5.231 GAS MEDIA
  - 5.2311 CONDUCTION, CONVECTION, AND RADIATION
- 5.232 SOLID
  - 5.2321 CONDUCTION
- 5.233 LIQUID
  - 5.2331 CONDUCTION AND CONVECTION

THERMAL ENERGY OR HEAT CAN BE TRANSMITTED IN ANY OF THREE WAYS: THROUGH CONDUCTION, THAT IS, THE VIBRATION CAUSED BY HEAT IS TRANSFERRED FROM ONEATOM TO ANOTHER UNTIL THE OBJECT IS EVENLY HEATED, OR POSSESSES THE SAME AMOUNT OF ENERGY THROUGHOUT THE OBJECT. THIS IS THE ONLY TYPE OF ENERGY TRANSFER POSSIBLE IN A SOLID. EXTERNALLY, SOLIDS, LIQUIDS, AND GASES WILL RADIATE HEAT ENERGY SINCE IT IS THE SAME AS LIGHT EXCEPT IT IS A LOWER FREQUENCY. GASES AND LIQUIDS, BECAUSE THEY ARE FREE TO MOVE POSSESS A THIRD TYPE OF TRANSFER CAPABILITY CALLED CONVECTION. AIR, FOR EXAMPLE, WHEN HEATED BECOMES LIGHTER, THUS IT RISES AND THE ENERGY IS TRANSPORTED THROUGH MECHANICAL MOVEMENT OF THE AIR ITSELF.

MANY MODERN INDUSTRIAL PROCESSES ARE HAMPERED BY THE INABILITY OF ANY OF THE ABOVE PROCESS TO MOVE SUFFICIENT QUANTITIES OF HEAT FROM OR TO A PARTICLAR DEVICE OR MACHINE.

A DEVICE INVENTED IN 1963 PROVIDES A MEANS OF MOVING HEAT THAT IS SEVERAL THOUSAND TIMES GREATER THAN THE BEST METAL CONDUCTORS SUCH AS COPPER AND SILVER. REFER TO VISUAL #4 FOR DISCUSSION. THE CONTAINER IS MADE OF SOME CORROSION RESISTANT MATERIAL SUCH AS COPPER OR STAINLESS STEEL, EVEN INSULATORS SUCH AS GLASS MAY BE USED THOUGH THEY ARE NORMALLY POOR CONDUCTORS OF HEAT. INSIDE THE TUBE IS A WICK MATERIAL SUCH AS A NICKEL MESH AND SOME WORKING FLUID SUCH AS WATER, SODIUM OR A HYDROCARBON. THE CHOICE OF ALL MATERIALS WILL DEPEND UPON APPLICATION. AT FIRST GLANCE THE PIPE APPEARS SIMILIAR TO A STEAM HEATING SYSTEM,

3

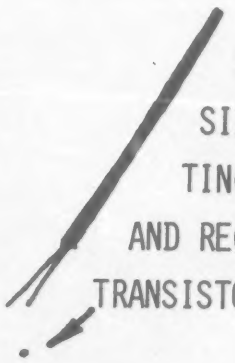
VISUAL #

WHY FIBER OPTIC COMMUNICATION?

1. LIGHT WAVES OSCILLATE THOUSANDS OF TIMES FASTER THAN RADIO WAVES, ABOUT 100 TRILLION TIMES EACH SECOND FOR INFRARED, MORE FOR VISIBLE LIGHT (SEE VISUAL #2). POTENTIALLY, A GLASS FIBER WILL CARRY 10,000 TIMES AS MUCH INFORMATION AS A COPPER WIRE.
2. WEIGHT - ONE POUND OF GLASS WILL DO THE WORK OF 2 TON OF COPPER.
3. COST - GLASS, MADE FROM THE MOST ABUNDANT ELEMENT ON EARTH WILL ONE DAY BE VERY CHEAP.
4. LESS COMPLEXITY IN END PRODUCT.

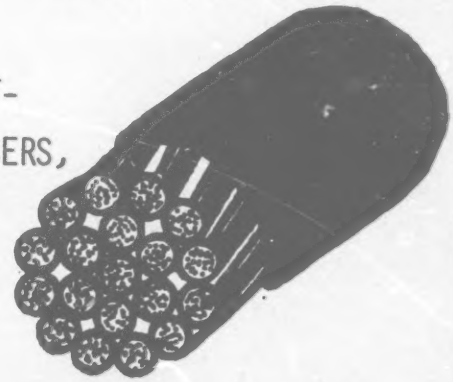
WHAT HAS MADE IT POSSIBLE?

ULTRA PURE GLASS - SO CLEAR THAT YOU COULD SEE TO THE BOTTOM OF THE PACIFIC IF IT WERE AS CLEAR



SALT GRAIN SIZE LIGHT EMITTING DIODES, LASERS, AND RECEIVING TRANSISTORS

CONVENTIONAL PHONE CABLE



POTENTIAL & ACTUAL APPLICATIONS

MEDICAL PROBES
INDUSTRIAL PROBES
NIGHT VISION GLASSES
PICTURE PHONES
AUTO INSTRUMENT DISPLAYS

INCREASED DATA TRANSMISSION WILL PERMIT:
SHOPPING AT HOME WITH TV
LEARNING AT HOME WITH TV
BUSINESS AT HOME WITH TV
TRAVEL AND INTERACTION THROUGH TV.

WHICH IT IS, BUT THE MAJOR DIFFERENCE IS THAT THE FLUID IS RETURNED FOR REHEATING BY CAPILLARY ACTION THROUGH THE WICK WHICH LINES THE CONTAINER WALL, THUS THERE IS A FANTASTIC MOVEMENT OF HEAT WITH NO MOVING PARTS. THE REASON THAT THE HEAT PIPE MOVES HEAT SO EFFECTIVELY IS THE FACT THAT WHEN A LIQUID VAPORIZES IT ABSORBS A LARGE QUANTITY OF HEAT KNOWN AS THE LATENT HEAT OF VAPORIZATION. THIS OCCURS BECAUSE ENERGY IS NEEDED TO SEPERATE THE MOLECULES THAT WERE ORIGINALLY IN CONTACT. ONCE VAPORIZED, THE FLUID CAUSES A PRESSURE DIFFERENTIAL BETWEEN THE TWO ENDS OF THE PIPE FORCING THE VAPOR AND THE HEAT TO THE COOLER END WHERE IT CONDENSES RELEASING HEAT. CAPILLARY ACTION MOVES THE LIQUID THROUGH THE WICK TO THE HOT END. A ONE INCH DIAMETER PIPE CAN MOVE SEVERAL THOUSANDS OF WATTS OF POWER A DISTANCE OF TWO FEET OR MORE, WITH A LOSS (TEMPERATURE DIFFERENCE) OF A FRACTION OF A DEGREE FROM ONE END TO THE OTHER. IF ONE CAN VISUALIZE A ONE INCH BY TWO FOOT COPPER BAR WITH A BLOWTORCH APPLIED TO ONE END, THE OTHER END WOULD REMAIN COOL ENOUGH TO HOLD WITH THE BARE HAND FOR SEVERAL SECONDS. EVEN AFTER SEVERAL MINUTES, THE COOL END OF THE BAR WOULD BE SEVERAL HUNDRED DEGREES COOLER THAN THE HOT END.

DEVICES TO DEMONSTRATE THE EFFECTIVENESS OF THE HEAT PIPE ARE AVAILABLE FROM SEVERAL SOURCES INEXPENSIVELY. IF YOU CANNOT LOCATE ONE, CALL OR WRITE MANUFACTURER DIRECT: HORIZON INDUSTRIES, 3625 HORIZON DRIVE, LANCASTER, PA. 17601 717-285-5096.

SEVERAL POSSIBLE APPLICATIONS OF THE HEAT PIPE ARE SHOWN ON THE VISUAL.

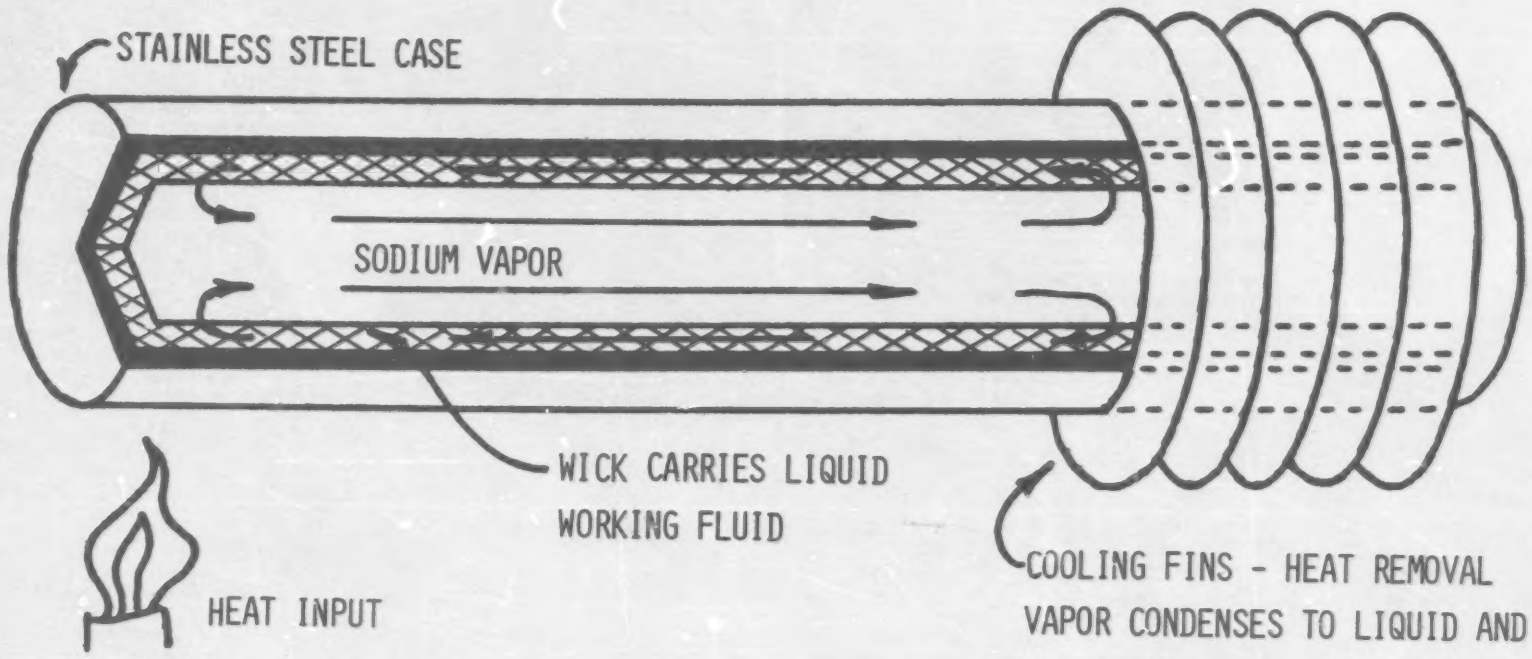
CURRICULUM GUIDE OUTLINE:

- 5.24 MECHANICAL ENERGY
  - 5.241 GAS MEDIA
    - 5.2411 WIND TURBINE (WINDMILL)
    - 5.2412 SAILS
    - 5.2413 PNEUMATIC DRIVEN AND PISTON DEVICES
  - 5.242 SOLID MEDIA
    - 5.2421 BELTS AND DRIVE CHAINS
    - 5.2422 CAMS
    - 5.2423 LEVERS
    - 5.2424 SCREWS
    - 5.2425 WHEEL AND AXLE
    - 5.2426 COUPLINGS
    - 5.2427 LINKAGES
    - 5.2428 EXPLOSIVES
  - 5.243 LIQUID MEDIA
    - 5.2431 WATER TURBINE
    - 5.2432 HYDRAULIC DRIVEN AND PISTON DEVICES

A NUMBER OF IDEAS FOR ACTIVITIES REGARDING MECHANICAL ENERGY TRANSMITTED THROUGH A GAS MEDIA CAN BE FOUND IN THE WIND ENERGY PACKET OF THE SCIENCE ACTIVITIES IN ENERGY.

LIKEWISE, A NUMBER OF ACTIVEITES REGARDING TRANSIMSSION OF MECHANICAL ENERGY THROUGH LIQUIDS CAN BE DEVISED USING AN INEXPENSIVE HYDRAULIC JACK, AND SMALL WATER PUMPS OF THE TYPE ATTACHED TO AN ELECTRIC DRILL, OR EVEN A SMALL SIPHON PUMP.

HEAT PIPE OPERATION



POSSIBLE HEAT PIPE APPLICATIONS

COOLING NUCLEAR REACTORS
COOLING SPACE CRAFT
COOLING ELECTRONIC COMPONENTS
TRANSPORTING HEAT IN SOLAR HEATING
COOLING EXOTIC ENGINES
COOKING FOOD EVENLY (PIPES INSERTED IN FOOD)
COOLING HIGH VOLTAGE COMPONENTS (HEAT PIPES CAN BE MADE OF INSULATORS LIKE GLASS)
MAINTAINING EVEN TEMPERATURES ON SENSITIVE COMPUTER COMPONENTS

LECTURE NOTES

VISUAL NUMBER 5 SHOWS THE BASIC MACHINES USED IN MECHANICAL TRANSMISSION OF ENERGY. VISUAL NUMBER 6 SHOWS SOME OF THE MANY MISCELLANEOUS DEVICES USED TO TRANSMIT ENERGY, MULTIPLY FORCE, SPEED OR REVERSE DIRECTION OF FORCE. VISUAL NUMBER 7 REVIEWS THE CLASSIFICATION OF LEVERS AND DISCUSSES THE CONCEPTS OF MECHANICAL ADVANTAGE AND VELOCITY RATIO. VISUAL NUMBER 8 CONTINUES WITH A DISCUSSION OF THESE CONCEPTS AS APPLIED TO PULLY SYSTEMS. VISUAL NUMBER 9 SHOWS A SIMPLE DEMONSTRATOR/EXPERIMENTOR THAT CAN BE USED TO VERIFY THE CONCEPTS PREVIOUSLY DISCUSSED.

CURRICULUM GUIDE OUTLINE:

5.25 CHEMICAL ENERGY
- 5.251 GAS MEDIA (FUEL CELL)
- 5.252 SOLID MEDIA (DRY CELL)
- 5.253 LIQUID MEDIA (WET CELL)

ONE MAY REFER TO PREVIOUS DISCUSSION ON THE ABOVE DEVICES. OF THE THREE LISTED, THE DRYCELL WAS NOT DISCUSSED AT ANY POINT IN EARLIER UNITS. ONE MAY MAKE A DEMONSTRATION DEVICE BY DISASSEMBLING A DRY CELL, OR BY PURCHASING A KIT WHICH HAS ALL THE MATERIALS TO MAKE ONE. A KIT OF THIS TYPE IS MARKETED BY IASCO (SEE APPENDIX).

CURRICULUM GUIDE OUTLINE:

5.26 NUCLEAR ENERGY
- 5.261 GAS MEDIA (REACTOR PRINCIPLE)
- 5.262 SOLID MEDIA (OBLATION PRINCIPLE)
- 5.263 LIQUID MEDIA

ONE CAN REFER TO THE FACT SHEETS IN UNIT THREE FOR REVIEW OF THE ABOVE PRINCIPLES. HOWEVER ONE SHOULD POINT OUT THAT NUCLEAR ENERGY IS NOT TRULY TRANSPORTABLE IN THE SAME SENSE THAT MECHANICAL ENERGY IS. THE REASON FOR THIS IS THAT WHEN RADIATION STRIKES ANY OBJECT THE ENERGY IS INSTANTLY CONVERTED TO HEAT JUST AS LIGHT IS WHEN IT STRIKES A COLLECTOR. THE PROBLEM THEN, IS ONE OF MOVING HEAT AWAY FROM THE REACTOR TO PREVENT MELTDOWN AND TO OBTAIN USEFUL ENERGY. WE MUST RELY THEN ON THE NORMAL METHODS OF HEAT TRANSMISSION. ONCE AGAIN THIS IS A POSSIBLE APPLICATION OF THE HEAT PIPE.

CURRICULUM GUIDE OUTLINE:

5.30 CONTROL SYSTEMS
- 5.31 SENSING AND SENSORS (FOR CONTROL PURPOSES)
  - 5.311 SENSED INFORMATION
    - 5.3111 QUANTITATIVE SENSING
    - 5.3112 QUALITATIVE SENSING
  - 5.312 CHEMICAL SENSORS
    - 5.3121 PH METER (SENSES ION CONCENTRATION)
    - 5.3122 GALVANOMETER (SENSES POTENTIAL BETWEEN METALS IN AN ELECTROLYTE SOLUTION)
    - 5.3123 SMOKE DETECTORS
  - 5.313 ELECTRICAL SENSORS
    - 5.3131 RELAY (SENSES QUANTITY OF CURRENT)
    - 5.3132 GALVANOMETER (SENSES MINUTE VOLTAGES)
    - 5.3133 AMMETER
    - 5.3134 OSCILLOSCOPE

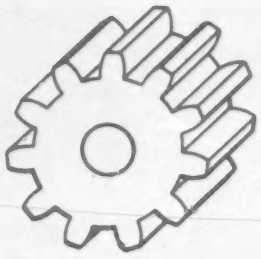
CONT'D P. 5 - 21

5

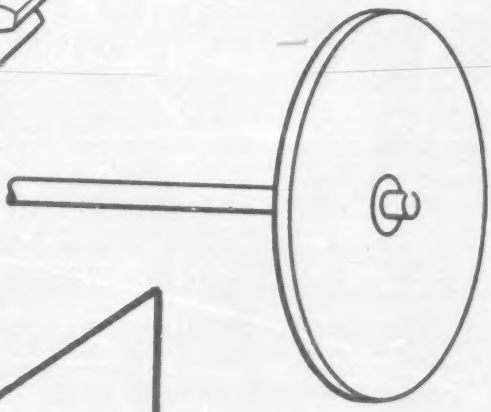
VISUAL #

THE SIX COMMONLY KNOWN BASIC MACHINES

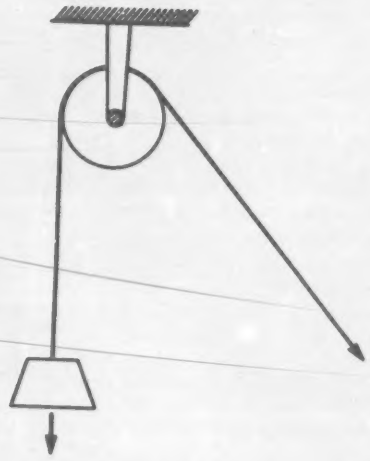
LEVER



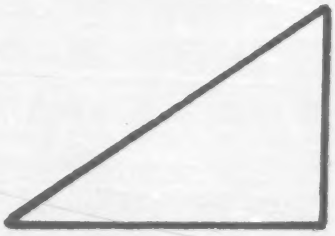
GEAR



WHEEL AND AXEL



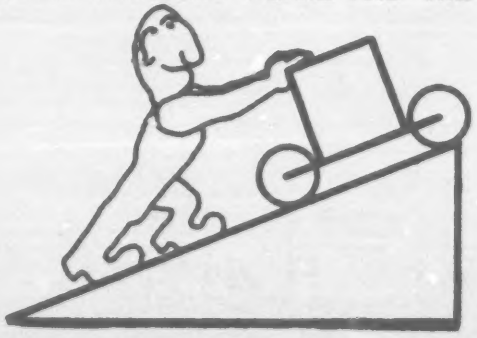
PULLEY



INCLINED PLANE

SCREW

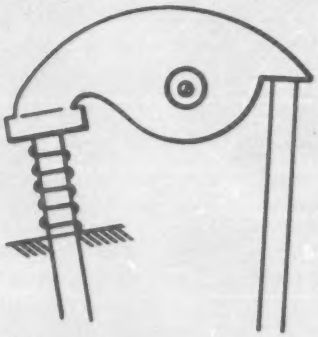
MACHINES HAVE MANY PURPOSES; TO TRANSFORM ENERGY, TO TRANSFER ENERGY, TO MULTIPLY FORCE, TO MULTIPLY SPEED, AND TO CHANGE DIRECTION OF FORCE. THE ABOVE SIX, AND MANY OTHER VARIATIONS ARE ALL DERIVED FROM THE SIMPLE INCLINED PLANE AND THE LEVER.



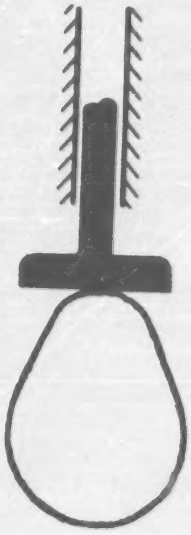
6

VISUAL #

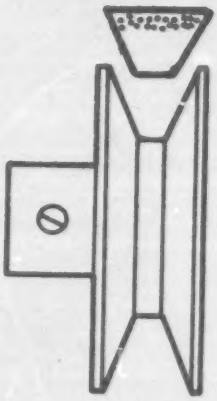
MISCELLANEOUS POWER TRANSMISSION DEVICES



LINKAGES AND CONNECTING RODS

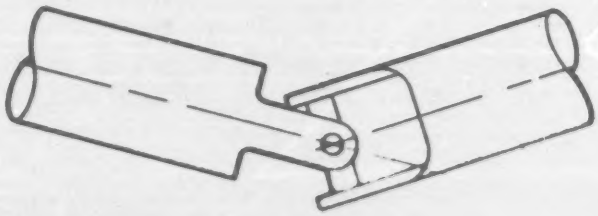


CAMS AND LIFTERS



BELTS AND PULLEYS

CHAINS AND SPROCKETS



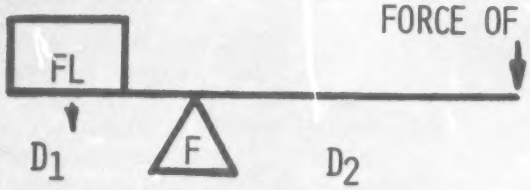
COUPLINGS AND U-JOINTS

7

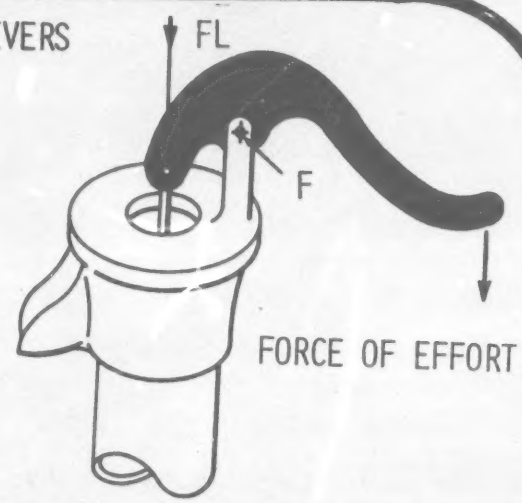
VISUAL #

CLASSIFICATION OF LEVERS

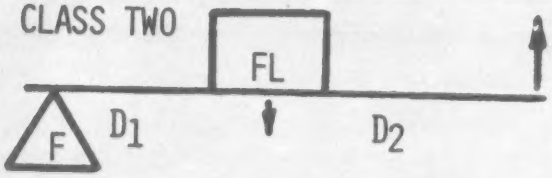
CLASS ONE



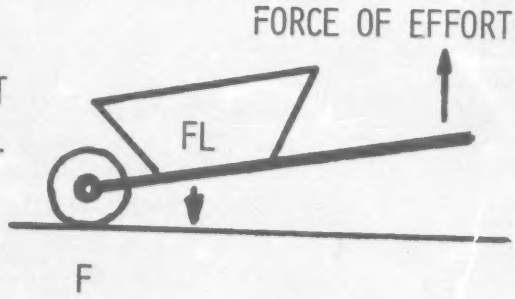
IN A CLASS ONE LEVER, THE FORCE OF EFFORT AND THE LOAD ARE ON OPPOSITE SIDES OF FULCRUM. LOAD FORCE X LOAD DISTANCE = FORCE OF EFFORT X DISTANCE OF EFFORT



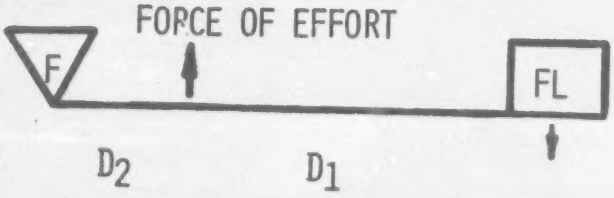
CLASS TWO



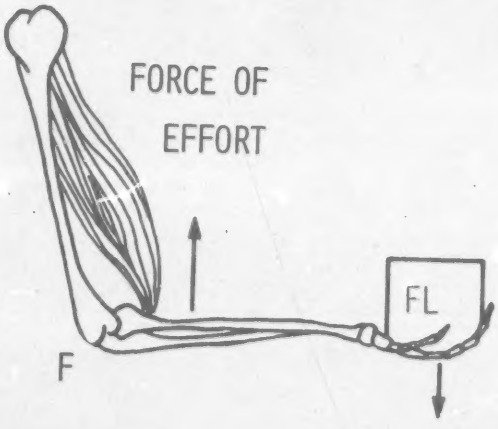
IN A CLASS TWO LEVER, THE FORCE OF EFFORT AND THE LOAD ARE ON THE SAME SIDE OF FULCRUM. LOAD FORCE X LOAD DISTANCE = FORCE OF EFFORT X DISTANCE OF EFFORT. AS IN THE CLASS ONE LEVER, FORCE IS MULTIPLIED.



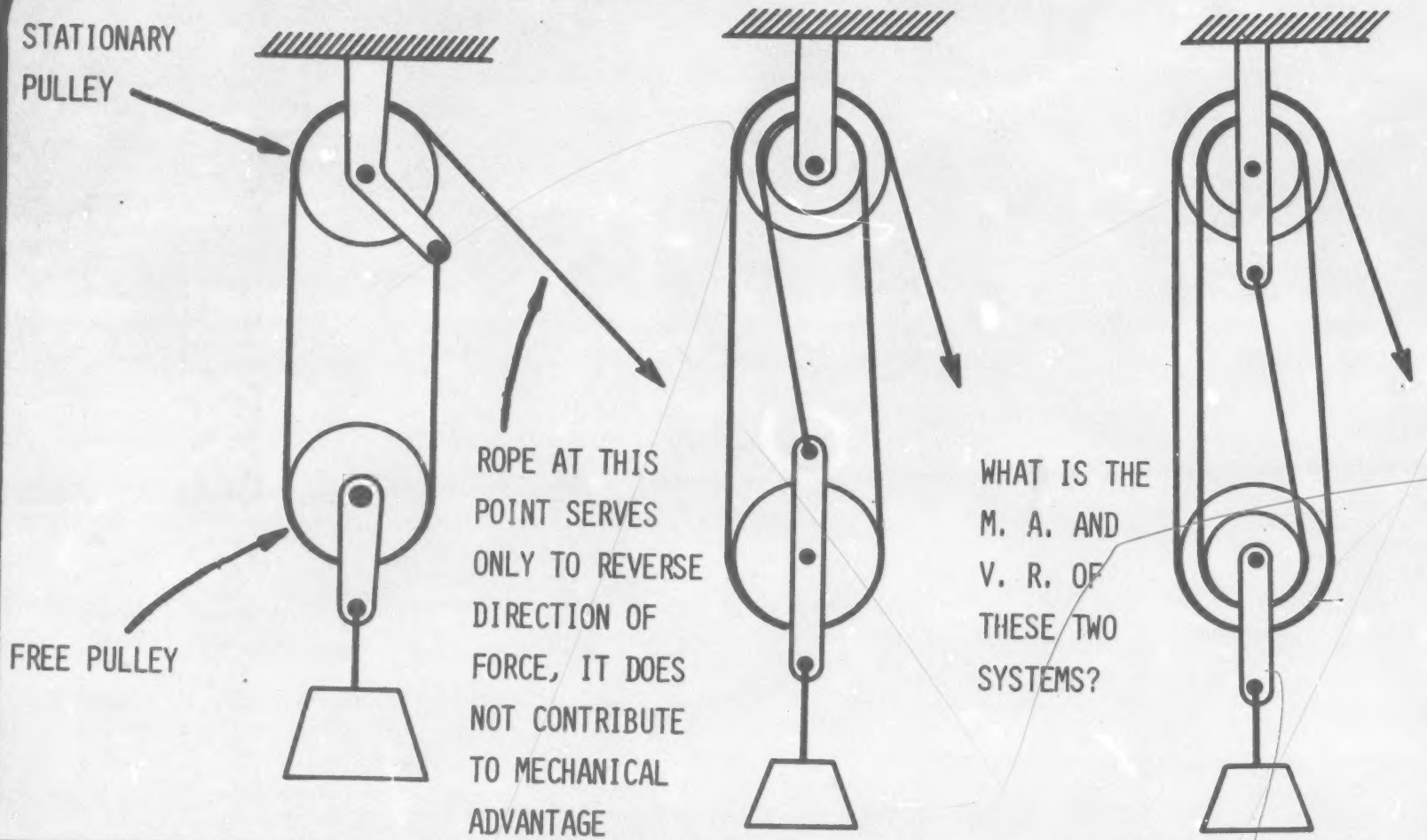
CLASS THREE



IN A CLASS THREE LEVER, THE LOAD AND EFFORT ARE ON THE SAME SIDE OF FULCRUM, BUT THE FORCE OF EFFORT IS CLOSEST TO FULCRUM CAUSING AN INCREASE IN DISPLACEMENT AND DECREASE IN FORCE



PULLEY SYSTEMS AND MECHANICAL ADVANTAGE


STATIONARY PULLEY
FREE PULLEY
ROPE AT THIS POINT SERVES ONLY TO REVERSE DIRECTION OF FORCE, IT DOES NOT CONTRIBUTE TO MECHANICAL ADVANTAGE
WHAT IS THE M. A. AND V. R. OF THESE TWO SYSTEMS?

NOTICE IN THE SYSTEM ON THE LEFT, THERE ARE TWO ROPES BETWEEN THE PULLEYS TO SUPPORT THE LOAD, SINCE EACH ROPE SUPPORTS ½ THE LOAD, SYSTEM MULTIPLIES FORCE BY 2. IT HAS AN M. A OF 2. ALSO, THE ROPE MUST BE PULLED TWICE AS FAR TO MOVE THE LOAD ½ AS FAR, THEREFOR SYSTEM HAS A VELOCITY RATIO OF 2. VELOCITY RATIO IS NUMERICALLY THE SAME AS MECHANICAL ADVANTAGE

VISUAL # 9

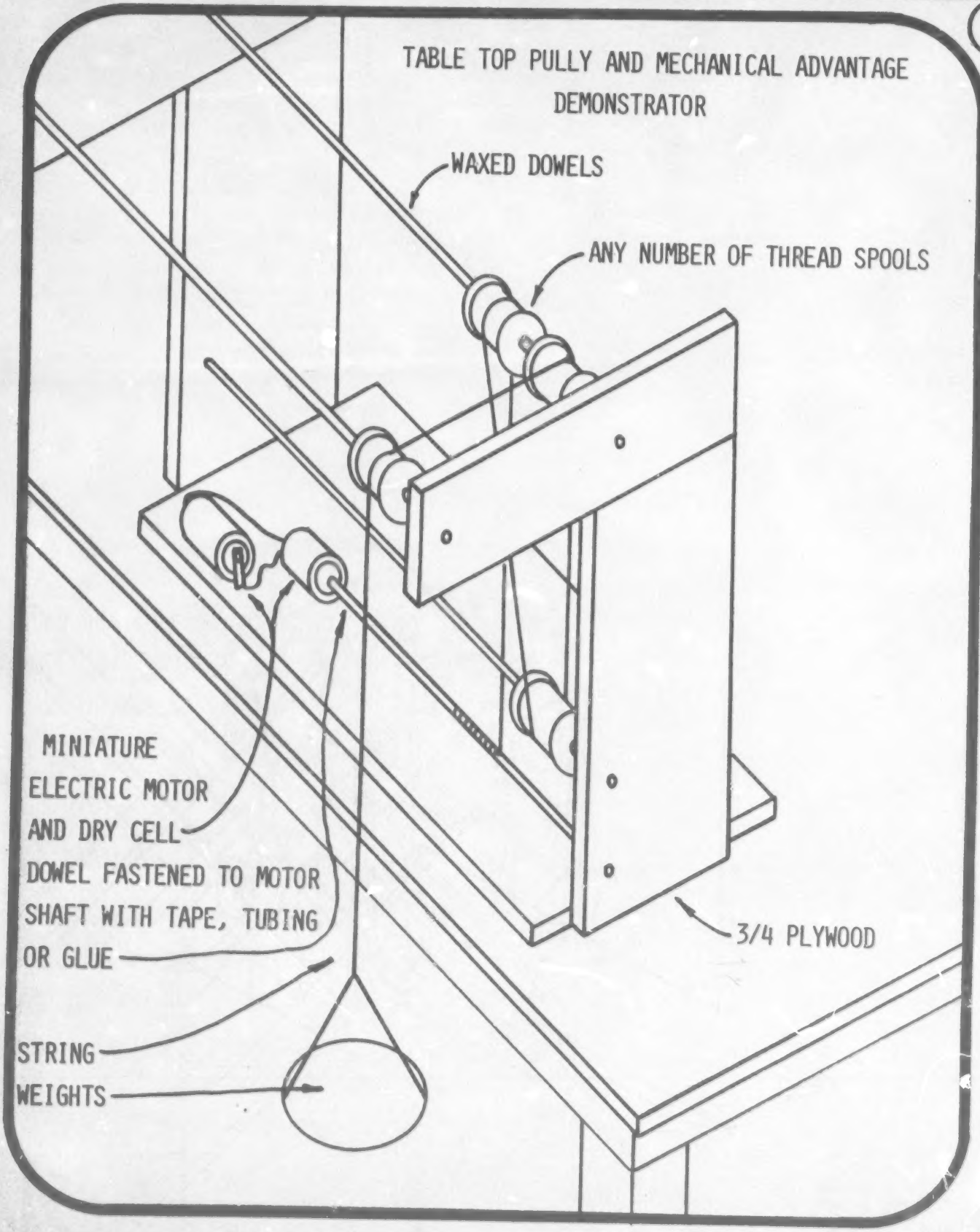


TABLE TOP PULLY AND MECHANICAL ADVANTAGE DEMONSTRATOR
WAXED DOWELS
ANY NUMBER OF THREAD SPOOLS
MINIATURE ELECTRIC MOTOR AND DRY CELL
DOWEL FASTENED TO MOTOR SHAFT WITH TAPE, TUBING OR GLUE
STRING
WEIGHTS
3/4 PLYWOOD

189

LECTURE NOTES

5.314 LIGHT SENSORS
- 5.3141 PHOTOVOLTAIC (SOLAR) CELL
- 5.3142 PHOTOCONDUCTIVE CELL

5.315 MECHANICAL SENSORS
- 5.3151 PLUMB BOB
- 5.3152 PROVING RING
- 5.3153 STRAIN GUAGE (POP-OFF VALVE. MANOMETER, ETC,)

5.316 NUCLEAR SENSORS
- 5.3161 GEIGER COUNTER

5.317 THERMAL SENSORS
- 5.3171 THERMOSTAT
- 5.3172 THERMOCOUPLE

REFER TO VISUAL # 10 FOR A DISCUSSION OF THE DIFFERENT TYPES OF CONTROL, OPEN AND CLOSED LOOP. NO DISCUSSION OF CONTROL WOULD BE COMPLETE WITHOUT MENTION OF MICROPROCESSOR CONTROL WHICH PROMISES TO AUTOMATE MUCH OF INDUSTRIAL PRODUCTION AND TO AFFECT ALL SEGMENTS OF INDUSTRY AND SOCIETY BY THIS ONE FUNCTION - CONTROL.

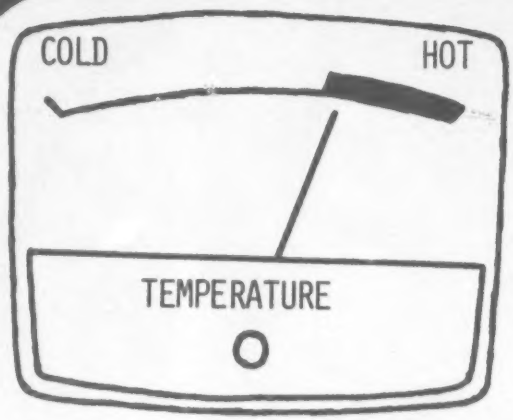
REFER TO VISUALS # 11, 12 FOR A LIST OF JUST A SAMPLING OF THE MANY TYPES OF SENSORS THAT ARE AVAILABLE AS NEW ONES ARE CREATED EVERY DAY. THERE IS A SENSOR THAT CAN DUPLICATE AND EXCEED MANS SENSES IN BOTH VARIETY AND SENSITIVITY. NOTE THAT MANY ARE ACTUALLY CONVERTORS SIMILIAR TO THOSE ALREADY STUDIED. FOR POSSIBLE ACTIVITIES IN CONTROL, REVIEW ALL PREVIOUS UNITS PLUS THE ATTACHED SCIENCE ACTIVITIES IN ENERGY.

ALSO A GOOD GROUP ACTIVITY IS TO HAVE STUDENTS BRING A SAMPLE SENSOR OR CONTROL ASSEMBLY TO THE CLASS FOR INCLUSION ON A LARGE DEMONSTRATION BOARD. WITH MICROPROCESSORS PROLIFERATING INTO ALL TYPES OF CONSUMER GOODS, STUDENTS SHOULD HAVE NO DIFFICULTY IN FINDING SEVERAL UNIQUE EXAMPLES EACH. THEY CAN SEARCH AUTO SERVICE CENTERS, SEWING MACHINE AND APPLIANCE REPAIR SHOPS FOR DEFECTIVE CONTROL DEVICES.

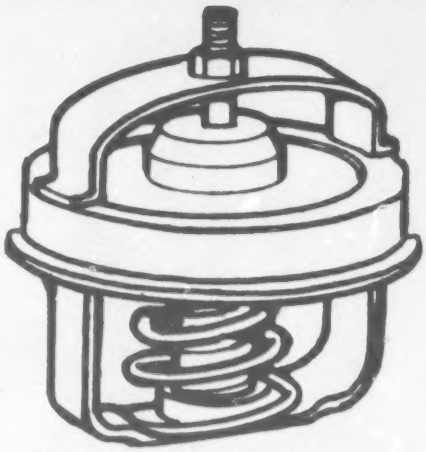
THE HOME AND AUTOMOBILE ARE LOADED WITH SUCH DEVICES.

10

VISUAL #

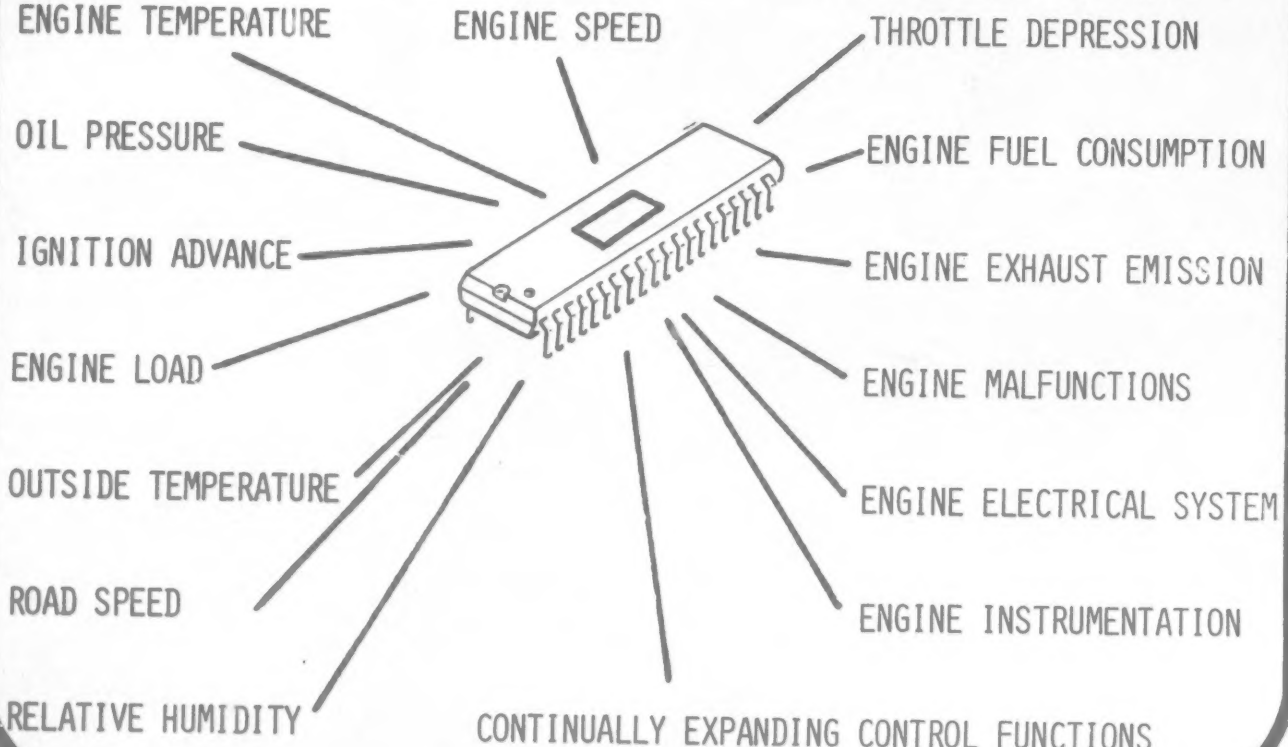


ENGINE TEMPERATURE GUAGE UTILIZES OPENLOOP CONTROL BY NOTIFYING OPERATER - ALSO CALLED INSTRUMENTATION



ENGINE THERMOSTAT AUTOMATICALLY REGULATES ENGINE TEMPERATURE - CALLED CLOSED LOOP CONTROL

MICROPROCESSOR CONTROL OF ENGINE FUNCTION UTILIZES OPEN LOOP CONTROL AND CLOSED LOOP CONTROL BUT RAISES AUTOMATION AND CONTROL TO A NEW LEVEL UTILIZING INPUT FROM DOZENS OF SENSORS AND CONTROLS SEVERAL VARIABLES



Process Variable	Sensing Device	Measuring Elements
Temperature	Thermocouple Thermistor Thermometer Bulb	Galvanometer or Bridge Bridge Network Bourdon Tube
Rate of Flow	Turbine Generator in Flow Path Magnetic Flowmeter Orifice Plate or Venturi Tube	Pulse Counter Galvanometer or Bridge Network Mercury Manometer and Float Diaphragm Using Balance, etc.
Strain, Torque, Tension and Force	Resistance Strain Gage	Bridge Network
Velocity	Fly-Ball Governor Tachometer Generator	Linkage and Points Electrical Deflecting Instrument or Network
Displacement or Position	Linear Potentiometer Rotary Potentiometer Capacitors Synchronous Transmitter Photo-electric Cell Flapper and Nozzle	Bridge Network or Electronic Network Electronic Network Synchronous Receiver Electronic Circuit
Pressure	Bourdon Tube Diaphragm Bellows	Motion-Potentiometers Linkage and Pointer

VISUAL # 12

Process Variable	Sensing Device	Measuring Elements
Level	Floats	Linkages and Pointer
	Electrodes	Electronic Networks
	Capacity Probes	Electronic Networks
	Photo-electric	Electronic Networks
	X-Ray	Sensitive Materials
	Radioactive	Geiger-Mueller-Tube
Thickness	X-Ray	X-Ray Sensitive Material
	Ultrasonic	Electronic Oscillators and Bridge Circuit
	Radioactive	Geiger-Mueller-Tube
Proximity	Magnetic Pickups	Electronic Circuit
	Photo Detectors	Photovoltaic, Photoconductive and Photoemissive Devices
Humidity	Hair Hygrometer	Thermometers and Electrical Bridge
		Electrical Circuit and/or Bridge
Density Conductivity and PH	Various Sensors	Electrical Bridges, etc.

unit 6
energy/power utilization

THE PURPOSE OF UNIT # 6 IN THE ENERGY/POWER CURRICULUM GUIDE, "ENERGY/POWER UTILIZATION" IS TO FOCUS ATTENTION ON SELECTED NEGATIVE AND POSITIVE ASPECTS OF SOME OF THE DECISIONS MADE IN REGARD TO THE TOPICS COVERED IN PREVIOUS UNITS. ATTENTION IS DIRECTED TOWARD THE ENVIRONMENTAL IMPACTS OF THE VARIOUS TECHNOLOGIES, AND THE EFFICIENT USE OF THESE TECHNOLOGIES IN SEVERAL SECTORS OF SOCIETY, NAMELY; RESIDENTIAL, COMMERCIAL, INDUSTRIAL AND TRANSPORTATION.

CURRICULUM GUIDE OUTLINE:

6.00 ENERGY/POWER UTILIZATION (EMPHASIS ON SAFE, EFFICIENT AND CONSERVATIVE USE IN ALL OF THE BELOW INDICATED APPLICATIONS).
- 6.10 RESIDENTIAL
  - 6.11 LIGHT ENERGY
    - 6.111 ILLUMINATION
    - 6.112 SENSING (ALARMS, ETC.)
    - 6.113 VIEWING (TV)
    - 6.114 ULTRAVIOLET LAMPS
  - 6.12 THERMAL ENERGY
    - 6.121 HEATING AND COOLING
    - 6.122 LIQUID AND FOOD REFRIDGERATION AND HEATING
    - 6.123 HEAT LAMPS
  - 6.13 MECHANICAL ENERGY
    - 6.131 MOTOR DRIVEN APPLIANCES AND TOOLS
    - 6.132 ENGINE DRIVEN DEVICES
    - 6.133 DOOR ACTIVATION MECHANISMS
  - 6.14 NUCLEAR ENERGY
    - 6.141 GASEOUS DETECTION
- 6.20 COMMERCIAL (SERVICES AND PRODUCTS ARE DISTRIBUTED)
  - 6.21 LIGHT ENERGY
    - 6.211 ILLUMINATION
    - 6.212 SENSING (ALARMS, ETC.)
    - 6.213 IMAGE DEVELOPMENT AND VIEWING (FILM DEVELOPMENT AND TV)
  - 6.22 THERMAL ENERGY
    - 6.221 HEATING AND COOLONG
    - 6.222 SUBSTANCE HEATING (OVNES, TORCHES, ETC.)
    - 6.223 DRYING
  - 6.23 MECHANICAL ENERGY
    - 6.231 PNEUMATIC DRIVEN (MOTOR, PISTON AND TURBINE DEVICES)
    - 6.232 HYDRAULIC DRIVEN (MOTOR, PISTON AND TURBINE DEVICES)
    - 6.233 ELECTRIC DRIVEN (SOLENOIDS, MOTORS, ETC.)
  - 6.24 NUCLEAR ENERGY
    - 6.241 MEDICAL AND FOOD TREATMENT
    - GASEOUS DETECTION
- 6.30 INDUSTRIAL (PRODUCTS ARE PRODUCED)
  - 6.31 LIGHT ENERGY
    - 6.311 ILLUMINATION
    - 6.312 SENSING
  - 6.32 THERMAL ENERGY
    - 6.321 CLIMATE CONTROL
    - 6.322 SUBSTANCE HEATING

6.33 MECHANICAL ENERGY
- 6.331 PNEUMATIC DRIVEN
- 6.332 HYDRAULIC DRIVEN
- 6.333 ELECTRIC DRIVEN

6.34 NUCLEAR ENERGY
- 6.341 INSPECTION
- 6.342 ELECTRICAL PRODUCTION

6.40 TRANSPORTATION

6.41 AIR OR SPACE
- 6.411 INTERNAL COMBUSTION (PISTON, ROCKET, TURBINE)

6.42 SURFACE
- 6.421 INTERNAL COMBUSTION ENGINES
- 6.422 EXTERNAL COMBUSTION ENGINES
- 6.423 ELECTRICAL
- 6.424 GRAVITATIONAL
- 6.425 MUSCLE

6.43 WATER
- 6.431 INTERNAL COMBUSTION ENGINES
- 6.432 NUCLEAR
- 6.433 MUSCLE
- 6.434 ELECTRICAL
- 6.435 WIND ROTOR

FOR A DISCUSSION ON MANY OFTHESE TOPICS REFER TO THE FACT SHEETS ON THE FOLLOWING PAGES: #17 - ALTERNATIVE ENERGY SOURCES - ENVIRONMENTAL IMPACTS, #9 - ENERGY CONSERVATION - HOMES AND BUILDINGS, #10 ENERGY CONSERVATION - INDUSTRY,#11 - ENERGY CONSERVATION - TRANSPORTATION, #18 - ALTERNATIVE ENERGY SOURCES - A GLOSSARY OF TERMS.

FOR A NUMBER OF CLASSROOM ACTIVITIES ON THE ABOVE TOPICS REFER TO "THE ENERGY CHALLENGE" (ATTACHED) A SERIES OF SPIRIT DUPLICATING MASTERS, AND THE SCIENCE ACTIVITIES IN ENERGY SERIES, THE PACKET ON CONSERVATION (ATTACHED).

FACTSHEET

National Science Teachers Association

17. ALTERNATIVE ENERGY SOURCES
Environmental Impacts

John M. Fowler

INTRODUCTION

As we have been forced to look more closely at the flow of energy into, through, and out of our industrialized society we have begun to understand that many of our environmental problems are energy-related. If we broaden our interpretation of the environment to include the society we live in, we must add health and sociological effects to the total. It is, of course, these latter effects, in the end, that make us pay attention to the energy-related damages to the natural system. They cost lives, interfere with industrial processes and recreation, damage our crops, our buildings and our belongings, and cost us money.

To properly treat all of the environmental, sociological, health and safety implications of the alternate energy technologies which are dealt with in this series of Fact Sheets is beyond the scope of these four pages. Since we have, in fact, summarized most of the major problems in the individual Fact Sheets, we will use this one to give a general overview. As a chronological framework, we employ the one used in the 1977 National Plan for Energy Research, Development and Demonstration (ERDA 77-1). The Plan lists three overriding objectives. Paraphrased, these three and their time scales are:

Short Term (1977-1985)	Reduce dependence on foreign oil
Medium Term (1985-2000)	Weather eventual decline in world oil supply
Long Term (2000+)	Development of renewable and essentially inexhaustible sources of energy

Short Term Developments in Energy and the Environment

In the short term, the Plan calls for a decrease in oil importation through conservation and by the conversion of power plants from oil to coal and uranium. The 2 million barrels per day (MBD) expected from the Alaskan reserves via the pipeline will also help reduce oil imports. The goal is to reduce imports from a projected 16 MBD in 1985 to 6 MBD.

The environmental impacts of this part of the plan will be mixed. Oil spills, for instance, and other forms of ocean oil pollution associated with tanker transport should be reduced. In 1975, a total of 1.65 billion tons (BT) of oil was transported around the world, 1.58 million tons (MT) of this ended up in the ocean, 0.19 MT by accidents and the rest through routine spills and discharges. Thus, for every MT of oil transported, 960 tons (on the average) end up in the sea, 115 tons by a tanker accident.

The 10 million barrel per day reduction, which is the Plan's target, amounts to a decrease in total imports in this country from 876 MT to 329 MT. This reduction should reduce total ocean pollution from 841,000 tons

1977

This material was produced by the National Science Teachers Association under contract with the U.S. Energy Research and Development Administration. The facts, statistics, projections, and conclusions are those of the authors.

to 316,000 tons, a savings of 525,000 tons. Spillage from tanker accidents should be reduced by 64,400 tons. For comparison, the "Argo Merchant," which was wrecked off Nantucket Island in the winter of '76-'77, spilled 31,000 tons of oil. Thus the targeted reduction in imports could spare us two "Argo Merchant" size wrecks.

This is the positive feature of the reduction in oil consumption. It will be somewhat offset by the environmental impact of the Alaskan pipeline -- an as yet unmeasured impact -- and by the increase in off-shore drilling and in coastal refineries which are projected. Added to its benefits is the slight improvement in air quality which achievement of the goal of a 10% reduction in gasoline consumption will bring about.

The conservation efforts should have, for the most part, benign environmental effects. When you don't use energy you don't need to extract, transport and convert it. The sociological effects of conservation may not be wholly benign. Energy price increases usually impact the poor more heavily than they do the affluent. Some small scale disruption of employment patterns may also result.

The two energy sources, coal and nuclear energy, whose development will be accelerated, will have some amount of adverse environmental impact. The environmental case is worse for coal. To increase the output from 655 million tons in 1976 to 1,225 million tons in 1985 means almost doubling coal's environmental impact if nothing further is done to lessen it. Most of the new coal will come from strip mining, and the additional 570 million tons expected to be mined in 1985 will require almost 200,000 new strip mined acres (at 3000 tons/acre). Unless sulfur removal devices are used when this coal is burned, the SO_x annually released to the atmosphere will also be almost doubled.

Increasing the output from nuclear power plants has its share of known and unknown impacts. To achieve the energy output projected in the President's Message, nuclear generating capacity must increase from 46,000 Mw at the end of 1970 to 340,000 Mw by 1985. A 1000 Mw reactor produces about 600,000 gallons of high level waste per year. The production of waste would rise from 27.6 million gallons in 1977 to 204 million gallons in 1985. Since this is twice the present liquid storage at the Hanford and Savannah River weapons plants it would appear that a full scale radioactive waste storage plan will have to be in full operation by then.

The increase in reliance on nuclear power will also increase the insecurity and anxiety of that portion of our populace which considers it unsafe. We have dealt with these problems in Fact Sheets #12 and #13.

New Mid-Term Environmental Problems

The new technologies which may begin to take on importance by 1985 and contribute during the mid-term period are coal conversion, oil shale, geothermal, bioconversion and two solar forms - heating and cooling, and windpower.

The first two of these - coal gasification and liquefaction, and oil from oil shale - present similar environmental problems. Perhaps the most serious is their need for water. We compare these needs below, in terms of gallons per million Btu's and include as well electric power plants.

Energy Installation	Energy (in billion Btu per day)	Water (in million gallons per day)	Gallons per Million Btu
1000 Mw coal-fired power plant*	61.4	10.3	170
1000 Mw nuclear (LWR)*	61.4	17.3	280
250 MCF coal gasification	236**	28	120
100,000 bbls/day coal liquefaction	580	18	31
100,000 bbls/day oil shale	580	16	28

Power plants with wet cooling towers are the most thirsty of the energy installations. The nuclear plants, since they do not discharge heat to the air through hot exhaust gas, as do the coal-fired plants, require more water. Coal gasification plants require water not only for cooling but also use steam as the source of hydrogen.

These water demands are going to be particularly troublesome in the central portion of the U.S., the belt running from Montana, the Dakotas and Wyoming down through Colorado and Utah to New Mexico and Arizona. The water demands of the new energy industries are going to clash with agricultural needs - for most of the agriculture in this region needs irrigation - and with the needs of the rapidly growing urban areas - particularly Phoenix and Denver.

* With wet cooling towers, 75% capacity factor.

** 250 x 10^6 cubic feet per day of 950 Btu/cf gas.

If the expected development of coal-fired power plants and coal gasification plants in the Dakotas and Wyoming takes place, most of this water will be supplied by the Upper Colorado Basin. Although the energy needs projected by the year 2000 will require only 7% of the Upper Basin's total runoff, it may be difficult to find even this relatively small amount.

Oil shale and coal conversion share other common problems. As mentioned in Fact Sheet #15, it has been found that synthetic fuels have molecules known as PCAH (polycyclic aromatic hydrocarbons) formed at high temperatures and there is ample evidence that many of these PCAH's are carcinogens. Research is underway to determine the extent of these hazards.

Both coal and oil shale conversion depend on mining large amounts of materials, (seven times as much shale as coal per Btu) and disposing of large amounts of waste. In coal conversion, in addition to the ash, the various by-products like sulfur will have to be disposed of. The oil shale problem will be more serious. For each 100,000 barrels of oil extracted about 150,000 tons of crushed rock will need disposal. There are also potential toxic air emissions from both technologies which will need control.

Environmental Problems in the Long Term

The three candidates for the long term replacement of the fossil fuels are the breeder reactor (with its associated light water reactors), fusion reactors, and solar electric generators. The potential for environmental impact seems to be in this same order from breeder to solar, but this reflects in part the fact that breeder technology is fairly well investigated, while the others are essentially unknown. We have discussed the environmental and social questions raised by the breeder in Fact Sheet #13. In this section we will briefly anticipate some of the problems which may arise when and if we near commercial success with either fusion or solar electric generation.

Fusion: At first glance, and if the comparison is with fission reactors, the environmental, health, and safety impact of large scale development of fusion reactors would seem to be small. Since only 50 to 60 kg of deuterium will be needed per year by a 1000 Mw fusion reactor, extraction of fuel should pose no particular problem. Hundreds of tons of deuterium per year are already being produced in this country. Lithium, the other fuel (tritium will be produced from it - see Fact Sheet #14) will also be needed only in relatively small quantities.

The fusion reaction does not produce the large variety of radioactive by-products characteristic of fission; tritium is the only one directly produced. Tritium could conceivably be released by some accident but the more routine threat comes from its ability to diffuse (leak) through metals. Since tritium is a fusion fuel, however, there will be strong motivation to design systems capable of trapping and recycling it.

The expectation of induced radioactivity in fusion reactors is the most troublesome of its direct environmental effects. There are also indirect effects which will have to be taken into account. The use of superconducting magnets on a large scale, for instance, will require large quantities of liquid helium and create a large demand for the rare superconducting metals. A different sort of indirect effect will be the requirement for a huge amount of electric power to start the reactor (for the magnetic field, the beam injection, etc.). In a large plant, power demand to start may be thousands of megawatts and larger than the present capacity of any existing generating plant.

Generally, fusion reactors will be high technology, capital intensive installations, and require a huge resource investment during their period of installation. This industrial and construction activity could also have environmental and social effects.

Solar Electric: Several forms of solar electric conversion are under development. Solar thermal (Fact Sheet #5), photovoltaic (Fact Sheet #4,) and ocean thermal (Fact Sheet #6) are three more or less direct conversion schemes, while wind energy conversion (Fact Sheet #3) and bioconversion (Fact Sheets #1 and #2) are indirect or secondary solar sources that also ultimately end up as electricity.

In addition to the difference between the conversion schemes, some of these systems are available at different scales and that also will effect their environmental impact. Photovoltaic generators, when they are perfected, can be dispersed over hundreds of acres for a large power station or can be employed as house-top units. Wind machines can be either huge machines laid out in a grid across a large part of the Midwest or can be a single unit powering a farm. It appears obvious that the environmental impact of the small dispersed units can be neglected. It is only the large scale application that will cause any concern.

The major environmental impact of the large scale systems is in land use. A 100 Mw central receiver plant will require a land area of 15-25 km^2 (3750-6250 acres). The collecting mirrors will cover about half of the surface area. This shading will change surface absorption and evaporation, lower surface temperature, and change surface wind patterns. It may, in fact, be beneficial, increasing moisture retention and encouraging vegetation. The land may be available for other uses such as grazing.

It is important that indirect effects of large

scale solar electric systems be anticipated and studied. To generate 40,000 Mw of electric power (about our present nuclear generating capacity) with photovoltaic cells of 12 percent efficiency, for instance, would require the production of about 1 million tons of high grade silicon. Annual U.S. production is presently about 500 tons. It will be important to find out what this production of silicon will cost the environment.

The construction and operation of a large solar electric generating plant may require bringing a fairly large number of people into a sparsely inhabited area and present some of the same sociological problems as would a coal-fired or nuclear plant.

Global and Climatic Impacts

Beyond the fairly local impacts of the various technologies lie the more vague but still disturbing hazards of global impacts or energy-related changes in climate. The new technologies are not specific culprits here; it is rather the growing worldwide use of energy whose effects must be monitored. There are at least two major concerns, the increase in atmospheric CO_2, which will come with increased combustion of the fossil fuels, and the change in radiation balance that could occur as we increase the amount of heat released at Earth's surface. Local climatic changes could also be brought about, by the enormous concentration of thermal energy at a nuclear energy park, for instance. Fortunately, it is still early enough to look ahead and anticipate problems before they arise.

Although the CO_2 content of the atmosphere has increased by 10 or 15 percent, its effect on the atmospheric temperature has not yet been as great as expected. But we have lots more fuel to burn, more than enough to double the atmospheric CO_2 content. It is predicted that such an addition could cause a 2° C increase in temperature and this would cause large and noticable changes in Earth's climate. Similarily our release of heat at the surface of the Earth is miniscule compared to the solar input, but 10 more doublings of earth consumption (and it has been doubling every 15 years) would bring our average release at the surface to the level of solar input. It is clear that we must stop all growth well short of this.

SUMMARY

All forms of energy conversion leave us with unwanted by-products, heat, air pollution, scarred land or contaminated water. The new technologies will not spare us this reckoning. Those that use the fossil fuels will need careful control. Burning always produces nitrogen oxides (a component of Los Angeles-style pollution), coal gives us sulfer, while oil leaves the hydrocarbons. If we turn to nuclear energy we face a different set of problems. It will be important, therefore, that well funded and extensive environmental and socioeconomic studies accompany the ongoing efforts to develop the new technologies. ERDA has requested $215 million for its Environmental Research and Safety programs in 1978 (the 1977 figure was $181 million). While most of this money is earmarked for fission-related environment, health, and safety studies, the scope includes all of the technologies. The results of these studies, most of them in advance of commercial commitment to the technological options, should have an important bearing on the developing energy policy.

Bibliography

1) "Social and Environmental Costs of Energy Systems." Budnitz and Holdren, "Health Effects of Energy Production and Conversion." Comar and Sagan, in Annual Review of Energy, Vol. 1. Jack M. Hollander, Editor, (Palo Alto, Calif.; Annual Reviews, Inc.) 1976.

2) Energy and the Environment, John M. Fowler (New York: McGraw-Hill) 1975.

3) "Western Water for Energy Development: Enough Water in the Right Place?", Energy, II, #2, pp. 4-7, Spring 1977.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

6 - 6

Copies of these Factsheets may be obtained from:
ERDA-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

FACTSHEET

National Science Teachers Association

9. ENERGY CONSERVATION Homes and Buildings

John M. Fowler

INTRODUCTION

Of the total of 71.1 quadrillion Btu's* of energy used in this country in 1975, about 30 percent, or 21.3 quadrillion Btu's, was used in the residential and commercial sectors. In these sectors, the major energy consuming unit is a building -- a home or apartment building, school, office building, theater, etc. and the major end use of the energy consumed was for heating and cooling. A breakdown of the various uses of energy in all sectors of the U.S. economy is shown in Table 1 below.

Table I
Breakdown of Energy Consumption
(As of 1968, latest available data)

End Use	Percent	End Use	Percent
Transportation	25	Air conditioning (b)	3
Space heating (b)		Refrigeration (b)	2
Residential	11	Cooking (b)	1
Commercial	7	Lighting (b)	
Process Steam (a)	17	Residential and	
Direct heat (a)	11	Commercial	2
Electric motors (a)	8	Other electric	
Raw materials (a)	6	industrial (a)	1
Water heating (b)	4	Miscellaneous	2
			100

(a) Industrial uses 43 percent
(b) Used in buildings 30 percent

We see that building related uses, space heating, water heating, air-conditioning, etc. account for 17 or 18 percent of the total.

The second piece of information needed to guide a conservation strategy is the efficiency of energy use or, conversely, the amount of energy that is wasted in a given consuming area. Such information is harder to obtain, but the intensive studies of energy consumption undertaken during the past few years have begun to provide it. Fortunately, for our conservation efforts, there is much room for improvement.

Modern buildings, with very few exceptions, were not designed to be energy conserving and some consume extraordinary amounts of the now precious stuff. The World Trade Center in New York is the extreme example. The 100,000 kw or so of power needed by this Center is more power than is required by Schenectady, N.Y., a city of 100,000 people.

Heat leaks through building walls and windows -- in during the summer, out during the winter. They are overlighted; they use energy consuming appliances; they are built of energy intensive materials.

*Btu, British Thermal Unit - an engineering unit for energy measurement. See the Glossary Fact Sheet, #18, for further definition.

This material was produced by the National Science Teachers Association under contract with the U.S. Energy Research and Development Administration. The facts, statistics, projections, and conclusions are those of the author.

CONSERVATION STRATEGIES AND SAVINGS

Energy can be saved in the construction of a building, in its operation, and by careful selection of the appliances within it.

Energy conservation in building structure: There are three major ways in which the structure of a building can influence energy use. The building materials themselves can be energy intensive or energy economic. The insulation, window area, and sealing determine its thermal properties. Finally, a building can be sited and oriented to make the most of natural heating and cooling.

The last of these has most applicability to private homes as their siting and orientation is the most flexible. Overhang can reduce the entrance of direct sunlight in the summer and allow it in the winter. Trees shade and cool; earth banks around Northern walls insulate. This customized design has limited usefulness on a national scale. For the individual consumer, however, an energy conserving design can have an important payoff.

The opportunities for energy savings in materials come out from the selection of energy economic materials over energy intensive ones. Architects point out that buildings are routinely overdesigned. The safety factors are much larger than reasonable; structural pieces are designed for mass production and ease of handling rather than efficient use of materials. Estimating that 10 percent of our total energy goes into building construction, some architects have suggested that 10 percent of this energy, one percent of the total could be saved without any loss in building safety or usefulness.

Much larger savings are available, however, if the buildings are designed to operate with less energy. The closest thing to an "energy conservation building code" are the Federal Housing Authority (FHA) standards. Up until 1971, these permitted heat losses as high as 50 Btu per square foot per hour -- almost 2,000,000 Btu, or the equivalent of 15 gallons of fuel oil per day. The 1971 standards became stricter (but apply only to new buildings).

Most homes built before 1965 have about 1-1/2" of insulating materials in the ceiling, none in the walls and floors, and plain windows (only about half of all single family homes currently have storm windows). Current practices call for 2" - 3" of insulation in the walls, 4" - 6" in the ceiling. An EPA report estimated that complete retrofitting of one third of the existing homes would save 0.5×10^{15} Btu's.

The energy savings which can be accomplished through insulation, weatherstripping, and adding storm windows to residences are accompanied by financial savings. Attic insulation, for instance, which most homeowners could install themselves, would cost about $200 in an "average" home (1,600 ft^2 of floor space) and would pay back this investment in 2 to 5 years (depending on climate).

The energy and therefore dollar savings to an individual home owner which should be expected for each of the recommended practices are summarized in the table below.

Table 2

Conservation Practice	Percentage Savings
1. Caulk and weatherstip doors and windows	10%
2. Install storm doors and windows	15%
3. Insulate the attic (6")	20%

For air conditioned houses, these practices will bring additional savings.

Energy savings with new homes are equally impressive. If all the 15.4 million living units projected to be built between 1972 and 1982 conformed to the 1971 FHA minimum insulation standards, rather than the 1965 standards, the total savings would be almost 3×10^{15} Btu, or 10 percent of the expected 1982 residential heating and cooling consumption.

The waste of energy in commercial buildings follows a similar pattern to that we have just examined in residences. Insulation and draft sealing is not significantly better. Air leaks or "infiltration" is particularly troublesome, accounting for 25 to 50 percent of the energy used in heating and cooling. In addition to leakage, there is over ventilation of a more or less deliberate type. Quite often the entire building is ventilated to the same level as is required in special areas such as bathrooms, kitchens, and conference rooms. It is estimated that reduction of excess ventilation alone could reduce fuel needs by 15 percent or so.

Energy conservation through reduced heating and cooling demand: The stragegies we have discussed so far require either some awkward and expensive "retrofitting" (putting in new insulation, etc.) or apply only to new building construction. There are, however, significant energy savings which are within reach, so to speak. They can be had for the twist of the thermostat control. Heat losses depend, not suprisingly, on the temperature difference across a thermal barrier -- be it wall or window. Thus the hotter the inside of the house, the easier it is to lose heat to the wintertime outside; the cooler the inside, the easier heat leaks in from the summertime outside.

This information can be turned into conservation figures. Lowering daytime temperatures from 74° F to 68° F and nightime from 66° F to 60° F will reduce wintertime heating needs by 15 percent, saving 15 out of every 100 heating dollars. If every U.S. household had lowered its wintertime temperature 6 degrees in 1975, it would have saved enough heat to provide heat for an additional 10 million houses, more or less, during the winter.

By raising the thermostat 6 degrees from 72° F to 78° F, cooling costs can be cut almost in half. If all homes had made this change in 1975, as much as 2 percent of the nation's total consumption of electricity could have been saved -- exactly the increase in electrical consumption between 1974 and 1975.

Lowered air conditioner demand has a double payback to the nation (and eventually to the consumer). The air conditioning load usually comes at the time of daily peak demand and often seasonal peak demand. Peak electricty is expensive electricity since the smaller, less efficient standby generators must be turned on to provide it. It is quite likely that future rates will reflect this cost and add economic motivation for thermostat twisting in the summer.

Conserving with appliances: Hot water heating and refrigerators together use 4 or 5 percent of household energy. An average dishwasher uses 14 gallons of hot water per load. One less load per week would save enough energy to heat 150,000 or so homes during the winter.

The automatically defrosting refrigerators are also energy greedy, using half again as much energy as those requiring manual defrosting. The automatic feature in some models can be switched off with resulting savings.

The appliance industry, in fact, presented a new look in Fall 1976, when not only the efficiency of the various models began to be displayed, but the typical annual energy use. The consumer is now able to base purchases not only on price, but on lifetime energy costs. Such information is especially useful on air conditioners, whose efficiencies vary by as much as a factor of three.

An old/new appliance which seems to be destined for importance is the heat pump. This device operates much like a reversible refrigerator; it "cools the outside" in the winter, pumping the heat indoors and can be turned around to cool the indoors in the summer. Heat pumps use 60 percent less electricity than do the usual electric resistance heaters in providing the same amount of heat.

Lighting: In the 1968 data of Table I, lighting represented a fairly small fraction of the total energy consumed, about 1.5 percent. Its percentage share is growing and accounts for a rather substantial fraction of electric energy consumption, 21 percent overall of the 1974 electrical consumption and as high as 60 percent of the electrical consumption in a city like New York.

Energy (and money) can, of course, be saved by turning out lights or by following the Federal Government's lead and removing each third bulb. (The FEA estimates that such a 30 percent reduction in lighting would save the average householder 4 percent of his or her electrical bill). Another way to improve the efficiency of energy utilization in lighting is to switch to the more efficient fluorescent bulbs whenever possible.

The major wasteful use of lighting, however, is in commercial buildings -- offices, schools, hospitals, etc. For reasons that seem to have no sound physiological basis, the illumination levels recommended by the Illuminating Engineering Society have been increased over the past two decades. In 1952, for instance, the recommended classroom lighting was 20 footcandles (a measure of brightness). This was raised to 30 in 1957 and to 60 in 1971. In libraries, the recommended level has gone from 20 in 1952 to 40 (1957), 50 (1959), and 70 in 1971.

Thus "no contrast" lighting has resulted in buildings in which all space, not just working space, is brightly lit and this includes walkways and even space near windows for which daylight would suffice. Estimates of possible

savings in electrical energy used for lighting in new buildings range upwards to 50 percent. A more realistic target of 25 percent in new buildings and 15 percent in existing buildings would reduce electrical demand by 4 percent (which is twice the rise in demand measured between 1974 and 1975).

SUMMARY

Buildings are involved, one way or another, in the consumption of about 30 percent of our total energy. They are thus a worthwhile target for the two-pronged goal of energy conservation — reduction in use and improved efficiency of utilization.

We mention many different target areas for building related energy conservation, including the use of less energy intensive materials and construction practices in the buildings themselves. Many of them we were not able to quantify on a national scale. Those conservation strategies which do have national numbers with them, however, add up to a significant sum. Bringing all insulation up to 1971 FHA standards and adding storm windows and weatherstripping could save about 40 percent of heating and cooling energy in the residential sector (about 4 percent of the U.S. total). For the commercial area, a cutback on excess ventilation could save 15 percent of their demand (another 1 percent of the total). Thermostat control, 6° lower in the winter and higher in the summer, could save another 15 percent (or 2 percent of the total).

All in all, a savings of 30 to 50 percent of the energy in the residential and commercial building sectors, and thus 14 percent of the U.S. total is not impossible to achieve. The ERDA goal for the year 2000 is to reduce energy demand in buildings by 7.1×10^{15} Btu. This is 4 or 5 percent of the 150×10^{15} Btu or so per year we are expected by some to be using in that year -- a not unreasonable goal.

Increasing our supply of usable energy by using it more wisely is the most appealing option we have. It can be brought in line relatively swiftly; it has generally positive environmental effects; it provides the least expensive energy and even saves the consumer money. While there are technological challenges to be met (a screw-in fluorescent bulb and better insulating material, for instance) the real challenges are in the institutional area, building codes, rate structures, tax laws. Breakthroughs accomplished in this social economic arena, therefore, are as important to our energy future as are the technological breakthroughs we have described in so many other Fact Sheets.

REFERENCES

1. Citizen Action Guide to Energy Conservation, Citizen's Advisory Committee on Environmental Quality, 1700 Pennsylvania Ave., N.W., Washington, D.C. 20006 (1973).

2. Tips for Energy Savers, Federal Energy Administration, (Washington: USGPO), 1975, (Order # 0-566-806).

3. "Energy Conservation", Hearing before the Subcommittee on Consumer Economics of the Joint Economic Committee, 93rd Congress, Nov. 19, 1973.

4. Hidden Waste, D.B. Large, Editor (Washington: The Conservation Foundation), 1973.

5. "Readings on Energy Conservation", Selected materials compiled by the Congressional Research Service for the Committee on Interior and Insular Affairs, U.S. Senate (Serial No. 94-1), (Washington: USGPO) 1975.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

FACTSHEET

National Science Teachers Association

10. ENERGY CONSERVATION
Industry

John M. Fowler

INTRODUCTION

The industrial sector is responsible for about 36 percent of our total energy consumption - 27.0 Q Btu* of the 1976 national total of 74.0 Q Btu. Since this is the largest share of the energy pie and particularly sensitive to the relation between Btu's and dollars, industry is undergoing thorough energy conservation analysis. Industrial energy consumption is also important because of the fuel mix; 41 percent of the natural gas, 18 percent of the oil, and 40 percent of the electricity (1976 figures).

While the industrial sector is a prime conservation target, it is so diverse that broad conservation strategies are difficult to find. It includes the steel industry with its coal-gulping blast furnaces and the less intensive garment industry. It has manufacturers of energy intensive plastics and makers of leather.

Although this Fact Sheet cannot cover all the industrial conservation options available, we can provide some perspective in the amounts and types of energy involved, give examples of conservation approaches in several of the energy intensive industries and summarize the possible savings throughout the sector.

RESOURCES

As in other conservation discussions (Fact Sheet #9 and #11), the resource considered here is not fuel reserves or fuel to be discovered, but commited resources to be saved. The targets are identified in the table below which shows industrial consumption by fuel.

The 1.35 billion barrels of oil in Table 1 represent 21 percent of the total U.S. consumption and more than half of the 2.58 Bbls of oil imported in 1976. The 8.21 trillion cubic feet of natural gas was more than the total used in the residential and commercial sectors. It must also be rememberd that additional gas and oil is consumed in the generation of electricity. The lower columns show the energy use per kilogram to produce specific materials. The high energy cost of aluminum, iron, copper, and the surprisingly high energy consumption in paper manufacture stand out and suggests recycling as an important strategy.

A recent projection of energy use (Bureau of Mines, 1975) anticipates an average annual energy consumption growth rate in the industrial sector of 2.3 percent. Thus, between 1975-1985, the industrial sector would be expected to use a total of 318 Q Btu. A 20 percent savings - a modest goal - would amount to 63 Q Btu, about the total energy consumed by the entire country in 1968. The "conservation resource" is one worth mining.

GENERAL CONSERVATION STRATEGIES

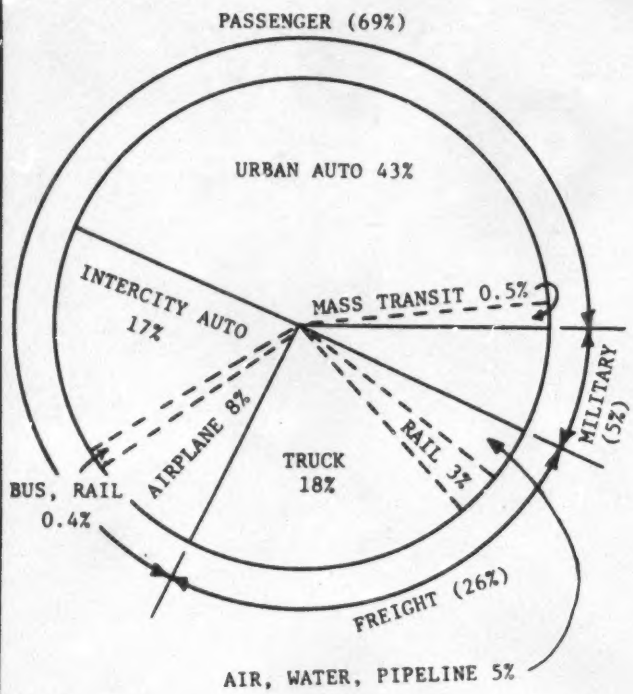
Generally, the conservation strategies in industry are of two types: reducing energy waste and improving efficiency. The first approach involves both leak plugging (better insulation, recovery of waste heat, adjusting equipment to high efficiency operation, etc.) and energy management (turning off lights, lowering thermostats, staggering work hours, etc.). Both

* See Glossary, Fact Sheet #18, for definition of energy units.

This material was produced by the National Science Teachers Association under contract with the U.S. Energy Research and Development Administration. The facts, statistics, projections, and conclusions are those of the authors.

LECTURE NOTES

Distribution of Transportation Fuel Uses-1972



ENERGY DATA FOR PASSENGER TRAFFIC - 1970

Inter-City

Mode	Average Passenger Capacity	Average Load Factor	Energy Cost (BTU per passenger mile)
Railroad	69/car	35%	2,900
Bus	41	45%	1,600
Automobile	5	48%	3,500
Airplane	106	50%	8,400

Urban

Mode	Average Passenger Capacity	Average Load Factor	Energy Cost (BTU per Passenger mile)
Bicycle	1	100%	200
Walking	--	--	300
Rail (Trolleys, Subways)	?	?	2,300
Bus	55	20%	3,800
Automobile	5	28%	8,500

Moving people efficiently: Transportation has two purposes, moving people and moving things. We spend the largest fraction of transportation energy on people. We have already discussed engine efficiency but a more pointed measure is the energy per passenger mile shown below.

The energy price we pay for speed and convenience is evident.

There are three strategies which can bring about more efficient passenger transport. "Load factors", the percentage of capacity carried in a car, plane, or bus, can be increased, engine efficiencies can be improved, and we can try to switch passengers from one mode to another (from the urban auto to mass transit, for instance).

Carpooling is an attempt to improve urban load factors from the present 28 percent (an average of 1.4 passengers in a 5 passenger car). The convenience of driving alone to work and the subsidized parking provided by many employers, however, works strongly against this improvement and little progress has been made.

The overall efficiency of a car as measured in miles per gallon (MPG) depends more on car weight and add-on systems such as air conditioning, automatic transmission and, lately, emission control, than on the engine itself. The national average has dropped over the years and was down to 13.9 MPG in 1974 as compared to 15.5 MPG in 1967. It improved slightly to 15.6 MPG in 1975 and rather dramatically to 17.6 MPG in 1976. While lighter smaller cars contributed to this improvement, a significant share of the credit belongs to the improvements in emission control due to the catalytic converter.

The improvements should continue, and the Federally mandated "sales weighted average"* of 20 MPG by 1980 and 27.5 MPG by 1985 should be achieved. Much of the improvement will be brought about by the reductions in weight; each 400 lb. reduction in a medium sized car produces about one MPG improvement. (Considerations of safety and rideability will ultimately limit this approach). We will eventually see new engine designs and are already seeing increased use of the more efficient diesel engine.

* "Sales weighted average" - The average MPG of all the cars sold by a given manufacturer in a certain year.

Changes in modes of travel could have significant effects but come slowly. The number of mass transit riders was 6 percent greater in 1974 than in 1973 but some of those passengers apparently shifted from walking rather than from automobiles. Mass transit, in fact, has such a small share of the market that even doubling its share will not make a big dent in energy consumption. New transit systems and improvement in older systems will likely have to be combined with penalties for automobile use before a shift to transit becomes an important part of the conservation picture.

The FEA estimates of possible savings (in bbls of oil/day) of three of the measures we have discussed are shown below. The total potential savings are greater than our present domestic oil production.

Energy Impacts of
Transportation Conservation Measures

Measure	Estimated Fuel Savings in 1980 (bl/day)
Increased new car fuel economy by 40% between 1974 and 1980 (20 MPG in 1980)	690,000
Increased rush-hour auto load factor from 1.2 to 1.6 (carpooling)	440,000
Double fraction of urban travel carried by transit from 2.5% in 1973 to 5% in 1980	52,000
	1,182,000

In intercity travel, the automobile is used a bit more efficiently, averaging 2.4 passengers. Shifting to trains or buses would still save considerable energy. Airplane travel is both the most energy intensive and the most rapidly increasing form of intercity travel. The reduction of airline routes and other measures introduced in the past few years have resulted in some savings, a 13% reduction in fuel use in 1974 over 1973 was reported. In the long run, we may have to approach energy conservation by marking out certain distances for different types of transportation, emphasizing autos for 100 miles or so, trains and buses for 100 to 500 miles and airplanes for the longer distances, for instance.

Moving things: The energy efficiency of various freight modes is shown below.

Mode	Energy Cost (Btu's needed per ton-mile)
Waterway	680
Pipeline (oil)	1,850
Railroad	700
Truck	2,800
Airplane (domestic)	62,000

The data shows the energy penalty we pay for the door to door delivery by truck and the speed of air freight. These are our most rapidly growing modes of freight transport.

We are somewhat limited in conservation strategies for freight transport. Load factors are already high in most cases. Trucks do get better gas mileage at 55 MPG (in spite of all the controversy) but they move less tons per mile per day this way. There are some aerodynamic improvements possible in truck design (reductions of air drag) which could save 10 percent or so of their fuel. Larger gains, however, would come from shifts between modes, from trucks and planes to trains, for instance.

NEW TECHNOLOGIES

In spite of the persistent rumors, there are no ultra efficient new engines hidden in the automobile companies' patent files. What we will see, in the near future, are many small improvements such as the electronic ignitions, stratified charge engines, etc. which are already being marketed. There is also considerable ERDA support for longer range improvements. A new, continuously variable transmission which could improve fuel economy by as much as 26 percent is under development. Two new engines, the gas turbine and the stirling engine are receiving much attention. In the gas turbine high velocity, hot gases from fuel combustion turn a turbine. A 100-horsepower version of this engine is being tested by Chrysler, in a compact car in 1977. The Stirling engine is an external combustion engine. The fuel is burned outside the cylinder and the hot, high pressure is then used to drive the piston. Both these engines have important advantages. They can burn any kind of fuel including non-petroluem fuels such as alcohol. They will be more efficient and much cleaner than the gasoline or diesel engines and will not require emission controls.

Electric cars: In many ways, the ideal engine for transportation would be electric. It is efficient, quiet, does not emit pollutants and does not use oil-based fuels. Although the electric vehicle has a long history, and is marketed today, it does not really compete with gasoline powered vehicles.

growing rapidly, energy conservation in this sector is of great importance.

The energy used to generate electricity can be conserved by reducing electrical consumption or by increasing either/both the primary fuel conversion efficiency or the efficiency of end use. While some reduction in the end use did take place in 1974 and 1975, growth resumed in 1976 and most projections show increasing reliance on electricity. Thus, there seems to be no doubt that the fraction of our total primary energy going into electrical generation will increase.

There are several strategies, however, which can increase the efficiency of generation and utilization of electricity. The leveling out of the peaks and valleys of the demand discussed in Fact Sheet #16 would accomplish this, as would the new rate structures which are being proposed to dampen peak load usage. There are also technological improvements in electrical generation under development. Improvements in electrical transmission, which still accounts for 10 percent or more loss, are being sought.

SUMMARY

The Industrial sector uses 36 percent of our yearly energy total. Its energy mix includes much natural gas, which is in short supply, and electricity, whose generation wastes much primary energy. It is thus, on all counts a prime target for conservation measures. A large variety of strategies could both lower consumption and improve utilization efficiency in this sector. There are management techniques - careful energy audits and controls - which have reduced consumption by 20 to 30 percent in several industries already. Waste heat recovery, recycling, and the application of new technologies can all help significantly.

The ERDA target for the year 2000 for conservation in the industrial sector is 8 Q Btu, plus another 4 Q Btu improvement in electrical generation and transmission efficiency. These 12 Q Btu would be about 8 percent of the 160 Q Btu consumption projected for 2000 - a modest target given the potential we have described.

The financial support for conservation comes from several sources. The Federal Energy Administration has been primarily involved in the application of existing strategies, while ERDA funds support research and development. The 1977 budget authority for ERDA in the conservation area came to $160 million out of a total of $3.01 billion. ERDA expenditures on conservation in the industrial and electric utility sector in FY 1977 are expected to total about $15.4 million.

The potential "resource" of conservation is large and the time lag for change-over to these strategies is much shorter than for any other technological option. Energy conservation has finally achieved a prominent place in this Administration's energy policy. The pressure of economics may force it to become a part of our national ethic.

BIBLIOGRAPHY

1. Annual Reviews of Energy, Vol 1, Annual Reviews, Inc. Palo Alto, California (1976). See especially "Raising the Productivity of Energy Utilization," Lee Schipper, pp. 455-518 and "Potential for Energy Conservation in Energy," Charles Berg, pp. 519-534.

2. SIPI Congressional Seminar on "Energy Conservation, Employment, and the Economy" October 20, 1975, available from Scientists Institute for Public Information, 355 Lexington Avenue, New York, New York 10017 ($2.00).

3. "Conservation in Industry," C.A. Berg, Science 184, pp. 264-271, April 19, 1974.

4. Hidden Waste: Potential for Energy Conservation, David B. Lange, editor (Washington: The Conservation Foundation) 1973.

5. Efficient Electricity Use, Craig B. Smith (New York: Pergamon) 1976.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
ERDA-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

11. ENERGY CONSERVATION
Transportation

FACTSHEET

Office of Education, Business & Labor Affairs

United States Department of Energy

INTRODUCTION

The transportation sector is a prime conservation target. It accounts for one quarter of our annual energy consumption, it uses energy inefficiently and primarily uses oil.

Of the 71.1 Q Btu* of energy consumed by the American economy in 1975, 18.5 Q Btu was used in transportation and 17.7 Q Btu (96 percent) was oil-derived; gasoline for automobiles, diesel fuel for trucks, trains, and buses, or kerosene for jet airplanes. The internal combustion engines which predominate in transportation are not very efficient, only about 15 percent of the fuel energy is actually used to move vehicles. It is not, of course, possible to build 100 percent efficient engines, but there is much room for improvement.

Transportation figured importantly in the conservation efforts of the '73-'74 Oil Embargo period. The national speed limit was lowered to 55 MPH and efforts were made to reduce the number of miles travelled. Both these efforts succeeded in part. The average speed of automobiles on interstate highways declined by 7.5 MPH in 1974 and total miles travelled during the first 8 months of 1974 were 4 percent lower than the similar period in 1973. Gasoline consumption was reduced by 3.4 percent. An appreciated side effect of the lowered speed was a 17 percent reduction (9,500 fewer deaths) in highway fatalities.

While the savings from these energy measures were important and continue to have an effect (the 55 MPH limit is still Federal Law) there are many other ways to reduce consumption.

RESOURCES AND STRATEGIES

The resources of this technology are the barrels of oil saved. The oil and oil-derived fuels used in transportation in 1976 was 20 percent more then we imported. As is shown in the illustration below, most of that fuel (60 percent) is used in automobiles and the automobiles' dominance has been increasing.

Urban and intercity passenger travel has doubled since 1950. Intercity bus transport has dropped from 5 percent of the total passenger miles in 1950 to 3 percent in 1970 and rail from 7 percent to 2 percent. Air travel, on the other hand, has increased. In urban travel, bus transport has dropped from 20 percent in 1950 to 2 percent in 1970. It is clear that many of the conservation strategies will focus on the automobile.

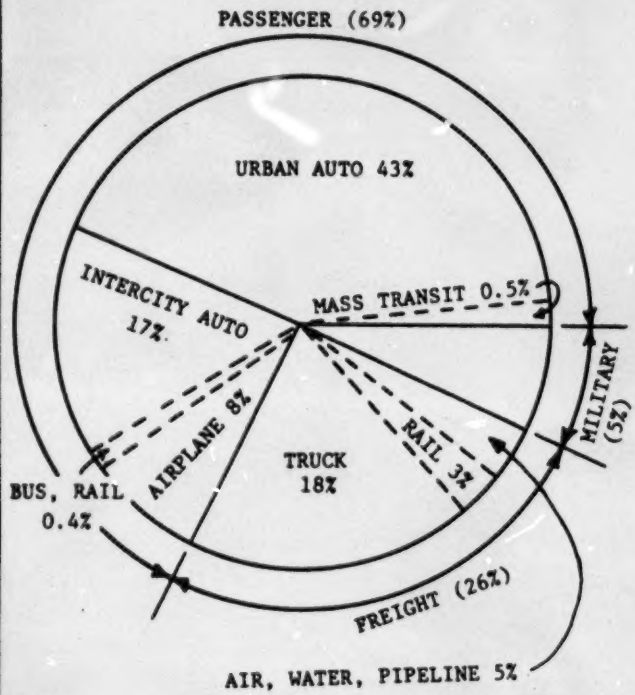
---

*Q, quadrillion Btu's. Energy units and other technical terms are described in the Glossary, Fact Sheet #18.

This material was produced by the National Science Teachers Association under contract No. EX-76-C-10-3841 with the Energy Research and Development Administration, now the U.S. Department of Energy. The facts, statistics, projections, and conclusions are those of the authors.

LECTURE NOTES

Distribution of Transportation Fuel Uses-1972



ENERGY DATA FOR PASSENGER TRAFFIC - 1970

Inter-City

Mode	Average Passenger Capacity	Average Load Factor	Energy Cost (BTU per passenger mile)
Railroad	69/car	35%	2,900
Bus	41	45%	1,600
Automobile	5	48%	3,500
Airplane	106	50%	8,400

Urban

Mode	Average Passenger Capacity	Average Load Factor	Energy Cost (BTU per Passenger mile)
Bicycle	1	100%	200
Walking	--	--	300
Rail (Trolleys, Subways)	?	?	2,300
Bus	55	20%	3,800
Automobile	5	28%	8,500

Moving people efficiently: Transportation has two purposes, moving people and moving things. We spend the largest fraction of transportation energy on people. We have already discussed engine efficiency but a more pointed measure is the energy per passenger mile shown below.

The energy price we pay for speed and convenience is evident.

There are three strategies which can bring about more efficient passenger transport. "Load factors", the percentage of capacity carried in a car, plane, or bus, can be increased, engine efficiencies can be improved, and we can try to switch passengers from one mode to another (from the urban auto to mass transit, for instance).

Carpooling is an attempt to improve urban load factors from the present 28 percent (an average of 1.4 passengers in a 5 passenger car). The convenience of driving alone to work and the subsidized parking provided by many employers, however, works strongly against this improvement and little progress has been made.

The overall efficiency of a car as measured in miles per gallon (MPG) depends more on car weight and add-on systems such as air conditioning, automatic transmission and, lately, emission control, than on the engine itself. The national average has dropped over the years and was down to 13.[illegible] MPG in 1974 as compared to 15.5 MPG in 1967. It improved slightly to 15.6 MPG in 1975 and rather dramatically to 17.6 MPG in 1976. While lighter smaller cars contributed to this improvement, a significant share of the credit belongs to the improvements in emission control due to the catalytic converter.

The improvements should continue, and the Federally mandated "sales weighted average"* of 20 MPG by 1980 and 27.5 MPG by 1985 should be achieved. Much of the improvement will be brought about by the reductions in weight; each 400 lb. reduction in a medium sized car produces about one MPG improvement. (Considerations of safety and rideability will ultimately limit this approach). We will eventually see new engine designs and are already seeing increased use of the more efficient diesel engine.

* "Sales weighted average" - The average MPG of all the cars sold by a given manufacturer in a certain year.

energy savings potential of co-generation could reach 2.1 Q by the year 2000. Implementation of industrial co-generation will add more than 50,000 Mw of low cost generating capacity (more than the 1976 nuclear capacity) and reduce the need for utility expansion.

Recycling: Table 2 suggests the conservation potential of recycling. Recycling could save 200 M Btu's per ton of aluminum, 12 M Btu's per ton of steel, and 42 M Btu's per ton of copper. According to EPA, 60 to 75 percent of aluminum used in this country could be recycled (4 percent is presently), and 90 percent of the steel (1.4 percent is at present).

A large percentage of solid waste is paper; if recycled, it requires only about one quarter the energy of virgin wood pulp. Although the amount of recycled paper used in the paper industry has decreased from 35 percent of the 1944 total to only about 20 percent now, its use is showing signs of growth. There are now three mills producing paper from waste paper and its use - and energy savings - is increasing.

Other valuable materials are wasted. Much of the waste from plastic manufacture has fuel value. Carbon monoxide is discharged in large quantities by several basic industries (e.g., iron smelting, aluminum, and phosphorous production). The feasibility of using this as a raw material for plastics manufacture is under investigation.

A specific example of recycling which shows the savings that can be obtained is in the "coil coating industry," which produces painted steel coils for appliance manufacture. Past practice has been to spray paint the coils and dry them in a natural gas-fired oven. In one experiment, the paint solvents, which normally go up the stack (as pollutants) are recaptured and burned to provide heat for the drying ovens. The use of natural gas in this plant was reduced by two-thirds.

CONSERVATION TECHNOLOGY

Within various industries there is much energy to be saved by the introduction of new processes and technologies. In the iron and steel industries, replacement of the open hearth furnace with the "basic oxygen furnace" at some plants has saved up to two-thirds of the energy formerly consumed. Likewise, the newer "continuous casting" process eliminates much of the heating and cooling, primarily saving natural gas.

The aluminum industry is a large user of electrical energy. Modifications in the electrolytic cells used in refining could, it appears, produce savings as large as 25 percent. An even newer chemical (instead of electrical) process has been announced which promises even larger (up to 50 percent) reduction.

High temperature heat energy is used to produce portland cement. A steam process that operates at a lower temperature has been demonstrated and could save a significant amount of energy (as much as 0.1 Q Btu in 1985). Changing the cement itself from pure portland to a blended mixture using inert material such as fly ash (as is presently done in Europe) would produce similar savings and is being studied.

APPLIED THERMODYNAMICS

One can, using the knowledge of thermodynamics (the study of heat and work), compute the "ideal' or theoretical efficiency of a heat engine in terms of the difference between the input and output temperature of the working fluid.* By comparing actual efficiences with this upper limit, engineers can find out how much additional improvement is possible. The maximum theoretical efficiency of a coal-fired plant, for instance, is about 60 percent and modern plants operate at 40 percent.

It is also possible to compute the minimum energy cost of manufacturing operations. From the limited application of such theoretical studies to actual industrial processes, it is clear that there is much room for improvement. In the manufacture of iron and steel, for instance, application of 1973-level technology would allow production at 18.8 thousand Btu/kg. The theoretical minimun is 6.6 thousand Btu/kg. The opportunities for improvements are even better in petroleum refining (3.6×10^3 Btu/kg at 1973 levels vs. a theoretical 0.5×10^3 Btu/kg), aluminum manufacture (167.6×10^3 vs. 27.7) and cement making (5.2×10^3 vs. 0.4). Paper manufacture which requires (1973 levels) 26.1×10^3 Btu/kg should require almost no energy according to thermodynamics.**

It will not be possible, of course, to achieve these theoretical minima, but they should serve as a challenge to engineers to make improvements in existing processes.

CONSERVATION IN THE ELECTRIC UTILITY INDUSTRY

The electric utilities industry is the largest user of primary energy. In 1976 it consumed 2.4 Q Btu's, 20 percent of the year's total. While 45 percent of that energy came from coal, 15 percent was from scarce natural gas and another 16 percent from oil. With an average generation efficiency of a little less than 33 percent, it takes 3 units of primary energy to produce 1 unit of this intermediate energy. Since industrial electrical consumption is

* See, for instance, Energy-Environment Source Book, Chapter 3, Volume II, John M. Fowler, NSTA, Washington, D.C., 1975.

** For a fuller treatment of these estimates, see reference in the bibliography of this Fact Sheet.

The major unsolved problem of the electric automobile is energy storage. The common lead-acid automobile storage battery is too heavy. It does not store enough energy per lb., cannot be discharged and recharged enough times, and is too expensive. Lead batteries account for 40-50 percent of the weight of existing electric vehicles and the set, which costs about $600, needs replacing every 3 years or so. We discuss in Fact Sheet #16, "Energy Storage Technology" new batteries, and the fuel cells, which may solve some of these difficulties.

Work is also ongoing on such refinements as "regenerative braking: slowing the vehicle by running the motor as a generator to recharge the battery. With its higher efficiency and the fact that it could largely draw on the nighttime capacity of large power plants, the use of electric autos in urban situations could save considerable energy. It has been estimated that for each one percent of urban passenger car miles taken over by electric cars, 4 billion kw-hrs of electricity would be consumed and 12.6 million barrels of gasoline saved. If it is further assumed that the electricity is produced in a relatively pollution-free way, the potential improvement becomes most attractive.

Other new technologies: By the next cantury, an even more interesting substitution of electricity in the transportation sector may take place - video communication instead of business flights. It appears that in many of the knowledge or information industries (insurance, finance, education, government, etc.) face-to-face telecommunicators may eventually replace physical meetings. The energy savings potential is great. It is estimated, for instance, that a gallon of gasoline used in an automobile is equivalent in energy to that required for 80 hours of telephone conversation. This may turn out to be the most practical way to replace gasoline by electricity.

SUMMARY

The transportation sector uses one quarter of our total energy directly (at an efficiency of about 15 percent), and as much as 40 percent of the total if indirect energy consumption is added in. It uses a premium and scarce fuel.

Many of the strategies we have described will require changes in attitudes and lifestyles in the private sector but even those which seemingly call for Federal intervention face a dispersal of responsibility across many Governmental Departments and Agencies.

ERDA has set aside, in FY77, $161 million for energy conservation, out of its $6.34 billion total budget. About $28 million of this is to be used to improve transportation efficiency largely through the development of new engines. The targeted goals of energy savings from more efficient use in transportation are 1 to 1.5 Q Btu in 1985 and 9 Q Btu in the year 2000. As we have said, it is quite likely that efforts along social and political lines could produce even greater savings than these purely technological ones. Considering transportation's negative contributions to energy consumption, to the oil shortage and air pollution, a national conservation effort in this sector is urgently needed.

REFERENCES

1. "Energy Conservation Training Institute", The Conservation Foundation, Washington, D.C., 1976 (see Part II and Part III, Chapt. 4).

2. "Energy Consumption for Transportation in the U.S.", Eric Hirst, Oak Ridge National Laboratory, ORNL-NSF-EP-15.

3. "System Energy and Future Transportation", Richard A. Rice, Technology Review, January 1972.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Source: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

6 - 18

Copies of these Factsheets may be obtained from:
DOE-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

Printed 1977
Reprinted September 1978

FACTSHEET

National Science Teachers Association

18. ALTERNATIVE ENERGY SOURCES
A Glossary of Terms

John M. Fowler and King C. Kryger

This glossary of terms is intended to accompany NSTA's Fact Sheets on alternate energy technologies. Although it should prove useful, independent of the Fact Sheets, it was not designed to provide a comprehensive listing of energy terms. Energy topics not covered in the Fact Sheets may be missing while specific technical terms that are defined within the text of individual Fact Sheets are not always included.

anthracite - "hard coal," low in volatile matter, high in carbon content, with a heat value of 6.40 million Calories/ton.

barrel (bbl) - A liquid measure of oil, usually crude oil, equal to 42 gallons or about 306 pounds.

base load - The minimum load of a utility (electric or gas) over a given period of time.

bioconversion - A general term describing the conversion of one form of energy into another by plants or microorganisms. It usually refers to the conversion of solar energy by photosynthesis.

biomass - Plant materials in any form from algae to wood.

bituminous coal - Soft coal; coal that is high in carbonaceous and volatile matter. It is "younger" and of lower heat value than anthracite or "hard coal." Heat value, 5.92 million Calories/ton.

black lung - A respiratory ailment, similar to emphysema, which is caused by inhalation of coal dust. Identified as a contributing cause in the deaths of many underground coal miners.

bottoming cycle - A means of using the low-temperature heat energy exhausted from a heat engine, a steam turbine, for instance, to increase the overall efficiency. It usually employs a low-boiling point liquid as working fluid.

breeder reactor - A nuclear reactor so designed that it produces more fuel than it uses. Uranium 238 ($_{92}U^{238}$) or thorium 232 ($_{90}Th^{238}$) can be converted to the fissile fuel, plutonium 239 ($_{94}Pu^{239}$) or uranium 233 ($_{92}U^{233}$), by the neutrons produced within the breeder reactor core.

British Thermal Unit (BTU) - An engineering unit of heat energy, the quantity of heat necessary to raise the temperature of one pound of water one degree Fahrenheit, about one-quarter of a Calorie.

Calorie - A metric unit of heat energy, the amount of heat that will raise the temperature of one kilogram of water 1° Celsius. It is approximately equal to 4 BTUs. (In scientific terminology it is equivalent to the kilocalorie, 1,000 small calories.)

This material was produced by the National Science Teachers Association under contract with the U.S. Energy Research and Development Administration. The facts, statistics, projections, and conclusions are those of the authors.

capacity factor - A measure of the ratio of the electrical energy actually produced at a generating plant to the maximum design capacity of the plant.

capital intensive - Requiring heavy capital investment. The energy industry, for example, is said to be capital intensive rather than labor intensive because it employs relatively more dollars than people.

carbon dioxide (CO_2) - A compound of carbon and oxygen formed whenever carbon is completely burned (oxidized).

carbon monoxide (CO) - A compound of carbon and oxygen produced by the incomplete combustion of carbon. It is emitted by automobiles and is, as far as total weight is concerned, the major air pollutant.

carcinogen - A substance or agent producing or inciting cancerous growth.

catalyst - A substance which changes the speed of a chemical reaction without itself being changed.

catalytic converter - A device added to the exhaust system of an automobile that converts the air pollutants carbon monoxide (CO) and hydrocarbons (HC) to carbon dioxide (CO_2) and water. A similar conversion also removes nitrogen oxides (NO_x).

Celsius - The metric temperature scale in which the temperature of melting ice is set at 0°, the temperature of boiling water at 100°. One degree Celsius is 9/5 of a degree Fahrenheit. The Celsius scale is also known as the Centigrade scale.

Centigrade - See Celsius.

chain reaction - A reaction that stimulates its own repetition. In a fission chain reaction a fissionable nucleus absorbs a neutron and splits in two, releasing additional neutrons. These in turn can be absorbed by other fissionable nuclei, releasing still more neutrons and maintaining the reaction.

char - A porous, solid, nearly pure carbon residue resulting from the incomplete combustion of organic material. If produced from coal, it is called coke; if produced from wood or bone, it is called charcoal.

chemical energy - A form of energy stored in the structure of atoms and molecules, and which can be released by a chemical reaction.

coal gasification - The conversion of coal to a gas suitable for use as a fuel.

coal liquefaction - The conversion of coal into liquid hydrocarbons and related compounds, usually by the addition of hydrogen.

coal tar - A gummy, black substance produced as a by-product when coal is distilled.

coke - Degassed coal (see char).

conduction - (of heat) The transmission of energy directly from molecule to molecule.

confinement time - (in fusion) The time during which the reacting materials (deuterium and tritium, for instance) are physically confined at proper density to react.

convection - (of heat) The transfer of energy by moving masses of matter, such as the circulation of a liquid or gas.

cooling towers - Devices for the cooling of water used in power plants. There are two types: wet towers, in which the warm water is allowed to run over a lattice at the base of a tower and is cooled by evaporation; and dry towers, in which the water runs through a system of cooling fans and is not in contact with the air.

critical mass - The smallest mass of fissionable material that will support a self-sustaining chain reaction under stated conditions.

crude oil - A mixture of hydrocarbons in liquid form found in natural underground petroleum reservoirs. It has a heat content of 1.46 million Calories/barrel and is the raw materials from which most refined petroleum products are made.

declining block rate - A method of charging for electricity wherein a certain number of kilowatt hours (the first block) is sold at a relatively high rate and succeeding blocks are sold at lower and lower rates. Thus the charge for energy decreases as the amount consumed increases. (See "inverted block rate.")

deuterium - A non-radioactive isotope of hydrogen whose nucleus contains one neutron and one proton and is therefore about twice as heavy as the nucleus of normal hydrogen, which consists of a single proton. Deuterium is often referred to as "heavy hydrogen"; it occurs in nature as 1 atom to 6500 atoms of normal hydrogen.

efficiency - The efficiency of an energy conversion is the ratio of the useful work or energy output to the total work or energy input. (This is sometimes called "First Law Efficiency.")

electrolysis - The decomposition of a substance by means of an electric current as in the production of hydrogen and oxygen from water.

electron - An elementary particle with a negative charge that orbits the nucleus of an atom. Its mass at rest is approximately 9×10^{-31} kg, and it composes only a tiny fraction of the mass of an atom. Chemical reactions consist of the transfer and rearrangement of electrons between atoms.

electrostatic precipitator - A device that removes the bulk of particulate matter from the exhaust of power plants. Particles are attracted to electrically charged plates and the accumulation can then be washed away.

energy - A quantity having the dimensions of a force times a distance. It is conserved in all interactions within a closed system. It exists in many forms and can be converted from one form to another. Common units are Calories, joules, BTUs, and kilowatt-hours.

energy intensiveness (EI) - A measure of energy utilization per unit of output. For passenger transport, for example, it is a measure of Calories used per passenger mile.

enrichment - A process whereby the percentage of a given isotope present in a material is artifically increased, so that it is higher than the percentage of that isotope naturally found in the material. Enriched uranium contains more of the fissionable isotope uranium 235 than the naturally occurring percentage (0.7%).

exothermic reaction - A reaction which releases more energy than is required to start it. The combustion reaction (burning) is an example as are fission and fusion reactions.

external combustion engines - An engine in which the fuel is burned outside the cylinders.

Fahrenheit - A temperature scale in which the temperature of melting ice is set at 32° and the temperature of boiling water at 212°. One Fahrenheit degree is equal to five-ninths of a Celsius degree.

fertile nucleus (or "fertile materials") - A material, not itself fissionable by thermal neutrons, which can be converted into a fissile material by irradiation in a reactor. There are two basic fertile materials, uranium 238 and thorium 232. When these fertile materials capture neutrons, they are converted into fissile plutonium 239 and uranium 233 respectively.

First Law of Thermodynamics - Also called the Law of Conservation of Energy. It states: Energy can neither be created nor destroyed.

fission - The splitting of heavy nuclei into two parts (which are lighter nuclei), with the release of large amounts of energy and one or more neutrons.

fluidized bed - A furnace design in which the fuel is buoyed up by air and some other gas. It offers advantages in the removal of sulfur during combustion.

fossil fuels - Fuels such as coal, crude oil, or natural gas, formed from the fossil remains of organic materials.

fuel cell - A device for combining fuel and oxygen in an electrochemical reaction to generate electricity. Chemical energy is converted directly into electrical energy without combustion.

fuel reprocessing - A recycling operation. Fissionable uranium and plutonium are recovered from uranium fuel rods which have undergone intense neutron bombardment in a nuclear reactor and fission products are removed.

fusion - The formation of a heavier nucleus by combining two lighter ones. In the reaction under study, as a source of energy hydrogen (or helium 3) nuclei combine to form helium 4 with a subsequent release of energy.

gasoline - A petroleum product consisting primarily of light hydrocarbons. Some natural gasoline is present in crude oil but most gasoline is formed by "cracking" and refining crude oil. It has a heat value of 1.32 million Calories/barrel.

generating capacity - The capacity of a power plant to generate electricity. Usually measured in megawatts (Mw).

geopressured reservoir - Geothermal reservoir consisting of porous sands containing water or brine at high temperature or pressure.

geothermal energy - The heat energy in the Earth's crust whose source is the Earth's molten interior. When this energy occurs as steam, it can be used directly in steam turbines.

greenhouse effect - The warming effect of carbon dioxide, CO_2, and water vapor in the atmosphere. These molecules are transparent to incoming sunlight but absorb and reradiate the infrared (heat) radiation from the Earth.

half life - The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of

years.

heat - A form of kinetic energy that flows from one body to another because of a temperature difference between them. The effects of heat result from the motion of molecules. Heat is usually measured in Calories or British Thermal Units (BTUs).

heat engine - Any device that converts thermal heat energy into mechanical energy.

heat pump - A device that transfers heat from a cooler region to a warmer one (or vice versa) by the expenditure of mechanical or electric energy. Heat pumps work on the same general principle as refrigerators and air conditioners.

heat value - The energy released by burning a given amount of the substance; also energy equivalent.

Helium 3 ($_2He^3$) - A rare, non-radioactive isotope of helium.

Helium 4 ($_2He^4$) - The common isotope of helium.

horsepower - Originally, the power output of a typical working horse. Equal to 3/4 of one kilowatt or 0.18 Calories per second.

hot rock reservoir - A potential source of geothermal power. The "hot rock" system requires drilling deep enough to reach heated rock then fracturing it to create a reservoir into which water can be pumped.

hydrocarbons - Molecules composed of carbon and hydrogen atoms in various proportions. They are usually derived from living materials.

hydroelectric plant - An electric power plant in which the energy of falling water is converted into electrical energy by a turbine generator.

hydrogenation - The addition of hydrogen to an organic molecule to increase the ratio of hydrogen to carbon, for instance in the production of oil from coal or from organic waste.

hydrothermal reservoir - One of the forms of geothermal reservoir systems. Consists of naturally circulating hot water or steam ("wet steam") or those which contain mostly vapor ("dry steam"). The latter type of hydrothermal reservoir is the most desirable type with present technology.

inertial confinement - One of two major techniques used in nuclear fusion experimentation. (See "Magnetic Confinement"). A frozen pellet of deuterium and tritium is bombarded from all sides by an energy source - a laser beam of charged particles. The resulting implosion of the pellet results in high temperature and density which allows ignition of the fusion reaction and the pellet explodes.

internal combustion engine - An engine in which power is generated within one or more cylinders by the burning of a mixture of air and fuel, and converted into mechanical work by means of a piston. The automobile engine is a common example.

in situ - In the natural or original position or location. In situ conversion of oil shale, for instance, is an experimental technique in which a region of shale is drilled, fractured, and set on fire. The volatile gases burn off, the oil vaporizes, then condenses and collects at the bottom of the region, from which it can be recovered by a well. There also has been some experimentation with in situ conversion of coal.

inverted block rate - A method of selling electricity wherein a first "block" of kilowatt hours is offered at low cost and prices increase with increased consumption.

ionization - Removal of some or all electrons from an atom or molecule, leaving the atom or molecule with a positive charge, or the addition of one or more electrons, resulting in a negative charge.

ions - Atoms or molecules with electric charges caused by the addition or removal of electrons.

isotope - Any of two or more species of atoms having the same number of protons in the nucleus, of the same atomic number, but with differing numbers of neutrons. All isotopes of an element have identical chemical properties, but the different nuclear masses produce different physical properties. Since nuclear stability is governed by nuclear mass, one or more isotopes of the same element may be unstable (radioactive). In the usual notation, isotopes of the same element are identified by the total of neutrons and protons in the nucleus, and the atomic number for example, uranium 235 ($_{92}U^{235}$) and uranium 238 ($_{92}U^{238}$).

joule - A metric unit of work or energy; the energy produced by a force of one newton operating through a distrance of one meter. One BTU = 1055 joules, and one Calorie = 4.185 joules.

kerosene - A petroleum distillate with a heat value of 1.43 million Calories/barrel presently used in gas turbines and jet engines.

kilocalorie - See Calorie.

kilowatt (kw) - A unit of power, usually used for electric power, equal to 1,000 watts, or to energy consumption at a rate of 1,000 joules per second.

kilowatt-hour (kw-hr) - A unit of work or energy. Equivalent to the expenditure of one kilowatt in one hour, about 853 Calories.

kinetic energy - The energy of motion. The ability of an object to do work because of its motion.

land subsidence - The sinking of a land surface as the result of the withdrawal of underground material. It results from underground mining and is a hazard of the development of geothermal fields.

laser - A device for producing an intense beam of coherent, sharply focused, light. The name is an acronym for Light Amplication by Stimulated Emission of Radiation.

Law of Conservation of Energy - See First Law of Thermodynamics.

Lawson Criterion - A rough measure of success in fusion. For a self-sustaining fusion reaction to take place, the product of the confinement time (in seconds), and the particle density (in particles per cm^3) must be about 10^{14}.

life cycle costs - The total cost of an item including initial purchase price as well as cost of operation, maintenance, etc. over the life of the item.

lithium - The lightest metal; a silver-white alkali metal. Lithium 6 is of interest as a source of tritium for the generation of energy from a controlled fusion reaction. Molten lithium will also be the heat exchanger.

liquified natural gas (LNG) - Natural gas that has been cooled to approximately -160°C, a temperature at which it is liquid. Since liquefaction greatly reduces the volume of the gas, the costs of storage and shipment are reduced.

load factors - The percentage of capacity actually utilized. For example, the average number of passengers for a certain size car divided by the passenger capacity of that size car.

magnetic confinement - A confinement technique used in nuclear fusion in which electrons are stripped from the reacting nuclei (deuterium and tritium, for example) forming a "plasma" which can be controlled by a magnetic field. There are several different types of magnetic confinement systems under development. (See "Tokamak," "magnetic mirror," and "magnetic pinch device.")

magnetic mirror - (See above) Consists of linear tubes in which the magnetic field confining a "plasma" is shaped so as to turn particles around at each end, as a mirror does a light beam. The most successful of these devices is the 2X-IIB at the Lawrence Livermore Laboratory of the University of California.

magnetic pinch device - (See above) - An interior space is filled with plasma which is then "pinched," or compressed by a magnetic field. This is accomplished by increasing the strength of the field and forcing the plasma toward the center of a tube. The Scyllac at Los Alamos is the major pinch device.

magnetic storage - a futuristic concept in which energy can be stored in a magnetic field around a superconducting material.

magnetohydrodynamic (MHD) generator - An expansion in which electricity is generated from the combustion of fuels without going through an intermediary steam turbine. Hot, partially ionized gases move through a magnetic field, and are separated by charge, generating a current that is then collected by electrodes lining the expansion chambers.

mechanical energy - One form of energy. It is observable as the motion of an object.

megawatt (mw) - A unit of power. A megawatt equals 1,000 kilowatts, or 1 million watts.

Methane Gas (CH_4) - A light hydrocarbon; an inflammable natural gas with a heat value of 257 Calories/cubic feet. Forms explosive mixtures with air. It is the major part of marsh gas and natural gas but can be manufactured from crude petroleum or other organic materials. (See coal gasification.)

Mev. - One million (or 10^6) electron volts - a unit of energy. It is equivalent to 1.6×10^{-13} joules.

MHD generator - See magnetohydrodynamic generator.

mill - A tenth of a cent. The cost of electricity is often given in mills per kilowatt hour.

moderator - A material used in a nuclear reactor to slow the speed of neutrons and thus control the rate of fission. Common moderators are graphite, water, deuterium, and beryllium.

molecule - Atoms combined to form the smallest natural unit of a substance. For example, the

water molecule is composed of two atoms of hydrogen and one atom of oxygen.

neutron - An elementary particle which is present in all atomic nuclei except for the most common isotope of hydrogen. Its mass is approximately that of a proton, but it has no electric charge. Neutrons are released in fission and fusion reactions.

Nitrous Oxides (NOx) - Compounds formed whenever combustion occurs in air (in the presence of nitrogen). An air pollutant and component of "Photochemical smog."

nuclear converter reactor - A reactor in which the major process is the conversion of fissionable fuel into energy as distinguished from a "breeder reactor" which produces more fuel than it uses. A converter reactor also "converts" some fertile material into fissionable fuel but produces less fissionable fuel than it consumes.

nuclear energy - The energy released during reactions of atomic nuclei.

nuclear reactor - A device in which a fission chain reaction can be initiated, maintained, and controlled.

nucleus - The extremely dense, positively charged core of an atom. It contains almost the entire mass of an atom, but fills only a tiny fraction of the atomic volume.

ocean thermal energy conversion (OTEC) - A process of generating electrical energy by harnessing the temperature differences between surface waters and ocean depths.

"off-peak" power - Power generated during a period of low demand.

oil shale - A sedimentary rock containing a solid organic material called kerogen. When oil shale is heated at high temperatures, the oil is driven out and can be recovered.

OPEC - The Organization of Petroleum Exporting Countries. An organization of countries in the Middle East, North Africa, and South America which aims at developing common oil-marketing policies.

particulates - The small soot and ash particles produced by combustion.

peak demand period - That time of day when the demand for electricity from a powerplant is at its greatest.

peak load - The maximum amount of power delivered during a stated period of time.

peak load pricing - Charging more for the delivery of power during the daily period which demand is the greatest. (See "peak demand period.")

petroleum - (or oil) an oily, flammable liquid that may vary from almost colorless to black and occurs in many places in the upper strata of the Earth. It is a complex mixture of hydrocarbons and is the raw material for many products.

photon - A quantum (the smallest unit) of electromagnetic radiation. It has no rest mass or electric charge, but behaves like both a particle and a wave in its interactions with other particles.

photosynthesis - The process by which green plants convert radiant energy (sunlight) into chemical potential energy.

Photovoltaic process - The process by which radiant energy is converted directly into electrical energy. Solar radiation striking certain materials is absorbed, causing separation of electrons from atoms. The migration of these electrons in one direction and of the positively charged electron vacancies ("holes") in the other can produce a small potential difference (or voltage), typically about 0.5 volts.

plasma - An electrically neutral, gaseous mixture of positive and negative ions. Sometimes called the "fourth state of matter," since it behaves differently from solids, liquids and gases. High temperature plasmas are used in controlled fusion experiments.

Plutonium (Pu) - A heavy, radioactive, man-made, metallic element with atomic number 94. Its most important isotope is fissionable plutonium 239 ($_{94}Pu^{239}$), produced by neutron irradiation of uranium 238. It is used for reactor fuel and in weapons.

potential energy - "Stored" energy. Energy in any form not associated with motion; such as that stored in chemical or nuclear bonds, or energy associated with the relative position of one body to another.

power - The rate at which work is done or energy expended. It is measured in units of energy per unit of time such as Calories per second, and in units such as watts and horsepower.

power gas - A mixture of carbon monoxide and hydrogen which has a low heat value (25-75 Calories/cubic feet) and is of most use as power plant fuel.

primary energy - Energy in its naturally-occurring form - coal, oil, uranium, etc. - before conversion to end-use forms.

proton - An elementary particle present in all atomic nuclei. It has a positive electric

charge. Its mass is approximately 1,840 times that of an electron. The nucleus of a hydrogen atom.

PSI - Abbreviation for "pounds per square inch." A measure of pressure.

pumped storage - An energy storage system in which reversible pump turbines are used to pump water uphill into a storage reservoir. The water can then be used to turn the turbines when it runs downhill.

Pyrolysis - Heating in the absence of oxygen. Also called "destructive distillation"; pyrolysis of coal produces three fuels: high BTU or pipeline gas, a synthetic crude oil (syncrude), and char, a carbon residue. Also used in the conversion of organic wastes to fuel.

radioactive decay - The spontaneous transformation of an atomic nucleus during which it changes from one nuclear species to another with the emission of particles and energy. Also called "radioactive disintegration."

reactor years - One year's operation of a nuclear reactor.

recoverable resource - That portion of a resource expected to be recovered by present-day techniques and under present economic conditions. Includes geologically expected but unconfirmed resources as well as identified reserves.

regenerative braking - Braking in which the energy is recovered either mechanically in a flywheel, for instance, or electrically. This energy can then be used in subsequent acceleration.

reserve - That portion of a resource that has been actually discovered but not yet exploited which is presently technically and economically extractable.

secondary recovery - Recovery techniques used after some of the oil and gas has been removed and the natural pressure within the reservoir has decreased.

Second Law of Thermodynamics - One of the two "limit laws" which govern the conversion of energy. Referred to sometimes as the "heat tax," it can be stated in several equivalent forms, all of which describe the inevitable passage of some energy from a useful to a less useful form in any cyclic energy conversion.

Second Law Efficiency - The ratio of the minimum amount of work or energy necessary to accomplish a task to the actual amount used.

solar cell - A device which converts radiant energy directly into electrical energy by the photovoltaic process. Each cell produces about 0.5 volts and about 0.6 watts of power.

solar energy - The electromagnetic radiation emitted by the sun. The Earth receives about 4,200 trillion kilowatt-hours per day.

solvent refined coal (SRC) - A tar-like fuel produced from coal when it is crushed and mixed with a hydrocarbon solvent at high temperature and pressure. It is higher in energy value and contains less sulfur or ash than coal.

Stirling engine - An external combustion engine in which air (or hydrogen in the newer versions) is alternately heated and cooled to drive the piston up and down. It is claimed to be non-polluting and more efficient than the internal combustion engine.

stratified charge engine - An engine in which the amount of charge, fuel plus air, is adjusted to engine conditions, directed to the area where it will burn best and fired at just the precise instant.

Strontium 90 ($_{38}Sr^{90}$) - A hazardous isotope produced in the process of nuclear fission. Strontium 90 has a "half-life" of 28 years. Thus it takes 28 years to reduce this material to half its original amount, 56 years to one quarter, 84 years to one eighth, and so on. Strontium 90 typifies problems of radioactive waste storage which are faced in producing power by means of nuclear fission.

sulfur smog (classical smog) - This smog is composed of smoke particles, sulfur oxides (SOx), and high humidity (fog). The sulfur oxide (SO_3) reacts with water to form sulfuric acid (H_2SO_4) droplets, the major cause of damage.

superconductor - A material which at very low temperatures, near absolute zero, has no electrical resistance and thus can carry large electrical currents without resistance losses.

snythetic natural gas (SNG) - A gaseous fuel manufactured from coal. It contains almost pure methane, CH_4, and can be produced by a number of coal gasification schemes. The basic chemical reactions are $C + H_2O + \text{heat} \longrightarrow CO + H_2$; $3CH_2 + CO \longrightarrow CH_4 + H_2O$.

tar sand - A sandy geologic deposit in which low grade, heavy oil is found. The oil binds the sand together.

tertiary recovery techniques - Use of heat and other methods to augment oil recovery (presumably occurring after secondary recovery).

thermal storage - A system which utilizes ceramic brick or other materials to store heat

energy.

thermodynamics - The science and study of the relationship between heat and other forms of energy.

thermostat - A temperature-sensitive device which turns heating and cooling equipment on and off at set temperatures.

Thorium (Th) - A naturally radioactive element with atomic number 90, and as found in nature, an atomic weight of approximately 232. The fertile thorium 232 ($_{90}Th^{232}$) isotope can be transmuted to fissionable uranium 233 ($_{92}U^{233}$) by neutron irradiation.

Tokamak - (toroidal magnetic chamber) The Russian adaptation of the toroidal or "doughnut" geometry. The plasma is confined in the central region of an evacuated doughnut-shaped vessel by a magnetic field provided by current-carrying windings around the outside. A separate set of windings produce a heating current in the plasma. American examples are the PLT (Princeton Large Torus) and the ORMAC (Oak Ridge Tokamak).

topping cycle - A means to use high-temperature heat energy that cannot be used in a conventional steam turbine. A gas turbine, for instance, might operate as a topping cycle on furnace gases of 2000°F and its exhaust could then heat steam for a turbine operating at 1000°F.

total energy system - A packaged energy system of high efficiency, utilizing gas fired turbines or engines which produce electrical energy and utilize exhaust heat in applications such as heating and cooling.

Tritium - A radioactive isotope of hydrogen with a half life of 12.5 years. The nucleus contains one proton and two neutrons. It may be used as a fuel in the early fusion reactors.

Uranium - A heavy, naturally occurring, radioactive nucleus of atomic number 92. Its most common isotope is 238_U ($_{92}U^{238}$), but 235_U ($_{92}U^{235}$, 0.7% of natural ore) is used as a fission fuel. $_{92}U^{233}$ which can be made from 232_{Th} ($_{90}Th^{232}$) is also fissionable.

uranium tails - Depleted uranium derived as a by-product of uranium enrichment. Depleted uranium has a smaller percentage of $_{92}U^{235}$ than the 0.7% found in natural uranium.

watt (w) - A metric unit of power usually used in electric measurements which gives the rate at which work is done or energy expended. One watt equals one joule of work per second.

work - Energy that is transferred from one body to another in such a way that a difference in temperature is not directly involved. The product of an external force times the distance an object moves in the direction of the force.

working fluid - The material, usually a gas or a liquid, whose absorption of heat and subsequent expansion drives a heat engine. Steam is the "working fluid" of a steam engine.

yellowcake - The material which results from the first processing (milling) of uranium ore. It is sometimes called "artificial carnotite" and is about 53% uranium, a mixture of UO_2 and UO_3.

Factsheet Titles

1. Fuels from Plants (Bioconversion)
2. Fuels from Wastes (Bioconversion)
3. Wind Power
4. Electricity from the Sun I (Solar Photovoltaic Energy)
5. Electricity from the Sun II (Solar Thermal Energy Conversion)
6. Solar Sea Power (Ocean Thermal Energy Conversion)
7. Solar Heating and Cooling
8. Geothermal Energy
9. Energy Conservation: Homes and Buildings
10. Energy Conservation: Industry
11. Energy Conservation: Transportation
12. Conventional Reactors
13. Breeder Reactors
14. Nuclear Fusion
15. New Fuels from Coal
16. Energy Storage Technology
17. Alternative Energy Sources: Environmental Impacts
18. Alternative Energy Sources: A Glossary of Terms
19. Alternative Energy Sources: A Bibliography

Copies of these Factsheets may be obtained from:
ERDA-Technical Information Center
P.O. Box 62, Oak Ridge, TN 37830

GPO 919-383

unit 7
energy/power
career opportunities

LECTURE NOTES

7.00 ENERGY/POWER CAREER OPORTUNITIES

CURRICULUM GUIDE OUTLINE:

- 7.10 PROFESSIONAL
  - 7.11 ENGINEER/DESIGNER
  - 7.12 INVENTOR
  - 7.13 RESEARCHERS/SCIENTISTS
  - 7.14 EDUCATORS
  - 7.15 EXECUTIVES/MANAGERS
- 7.20 TECHNICAL
  - 7.21 QUALITY/PRODUCTION SUPERVISOR
  - 7.22 ENGINEERING ASSISTANT
  - 7.23 SUPERINTENDENT/FORMAN
  - 7.24 DRAFTING/DESIGN PERSONNEL
  - 7.25 EXPERIMENTAL PERSONNEL
- 7.30 SKILLED
  - 7.31 ELECTRICIANS
  - 7.32 ASSEMBLERS
  - 7.33 MACHINISTS
- 7.40 SEMI-SKILLED
  - 7.41 ON-THE-JOB TRAINEES
  - 7.42 SELF-IMPROVED WORKERS
- 7.50 UNSKILLED
  - 7.51 HELPERS
  - 7.52 LABORERS
  - 7.53 ATTENDANTS

IN A GENERAL SENSE, WE HAVE ALREADY ACCOMPLISHED OUR OBJECTIVE IN REGARD TO CAREER PLANNING BY PROVIDING A BROAD EXPLORATORY EXPOSURE TO THE MANY AREAS OF ENERGY/POWER COVERED IN THE FIRST SIX UNITS. THE KEY TO SUCCESS IN FOCUSSING THE ATTENTION OF THE STUDENTS ON CAREER PLANNING AND DECISION MAKING AT THIS POINT LIES IN ENLISTING THE HELP OF PROFESSIONALS AND INTERESTED PARTIES IN MAKING AVAILABLE THE ADVICE, MATERIALS AND RESOURCES AT THEIR DISPOSAL.

A GOOD PLACE TO BEGIN IS WITH THE SCHOOL COUNSELOR. ASK FOR SUGGESTIONS FOR CLASS ACTIVITIES, GAMES ROLE PLAYING AND APPROPRIATE POINTS THAT NEED TO BE COVERED. ASK FOR ACCESS TO THEIR MEDIA CATALOGUES FOR FILMSTRIPS AND SLIDESETS ON THE TOPICS TO BE COVERED. NEXT INVOLVE YOUR LIBRARIAN. ASK FOR MATERIALS AVAILABLE TO THEM INCLUDING FREE LOAN AND INTER-LIBRARY LOAN. OBTAIN COPIES OF STATE FILM LIBRARY CATALOGS AND THE VOCATIONAL EDUCATION FILM AND CURRICULUM LIBRARY LOCATED AT BISMARCK JUNIOR COLLEGE. WRITE OR CALL THE STATE ENERGY OFFICE FOR ANY CAREER MATERIALS THEY MAY HAVE AND ALSO FOR THE NAMES OF PUBLIC RELATIONS OFFICIALS ASSOCIATED WITH THE MANY UTILITY COMPANIES AND ENERGY-RELATED INDUSTRIES IN NORTH DAKOTA. CONTACT THESE COMPANIES AND ASK FOR POSTERS, MATERIALS, SPEAKERS, ARRANGE FOR FIELD TRIPS ETC.

LECTURE NOTES

IN THE CLASSROOM THE BUSINESS OF GENERATING CAREER AWARENESS MUST BE ATTACKED WITH THE SAME VIGOR AND METHODS USED IN GENERATING SAFETY AWARENESS AND RESPONSIBILITY. (REFER BACK TO UNIT 2) AFTER ALL, A CAREER DECISION, NEXT TO THE IMMEDIATE SAFETY AND HEALTH OF THE STUDENT, IS OF PRIMARY IMPORTANCE.

FIRST, CREATE A VISUAL ENVIRONMENT, OBTAIN SLOGANS AND POSTERS FROM THE MANY SOURCES LISTED ABOVE. INFORM STUDENTS OF THE CONSEQUENCES OF THE LACK OF RESPONSIBLE CAREER DECISION-MAKING. ASK STUDENTS TO INTERVIEW PARENTS ABOUT HOW THEY CHOSE THEIR CAREERS. THE RESULTS MAY BE BOTH EYE-OPENING AND SAD. SOME PARENTS MAY COME TO CLASS, SOME MAY ALLOW THEMSELVES TO BE INTERVIEWED BY THEIR CHILDREN ON A CASSETTE RECORDER TO BE PLAYED IN CLASS. HAVE CHILDREN INTERVIEW WITH A CASSETTE RECORDER INDIVIDUALS INVOLVED IN THE MANY OCCUPATIONS LISTED IN THE CURRICULUM GUIDE OUTLINE.

FINALLY, STRESS THE OPPORTUNITIES AVAILABLE AND THE FACT THAT THEIR OWN ATTITUDES ARE OFTEN THEIR MOST SERIOUS HANDICAP TO ENTRY INTO A CAREER THEY DARE NOT HOPE FOR. TEACHERS ARE OFTEN, FOR MANY REASONS RELUCTANT TO "BLOW THEIR HORN" ABOUT THEIR CAREER AND PROFESSIONAL CAREERS IN GENERAL. DON'T SHORT CHANGE YOUR STUDENTS BY SLIDING PAST THESE OPTIONS. AN ENTHUSIASTIC ATTITUDE CAN BE HELPFUL TO BOTH TEACHER AND STUDENT.

appendices

APPENDIX A

REFERENCES

BIBLIOGRAPHY

FACTSHEET, ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION, NOW THE U.S. DEPARTMENT OF ENERGY - JOHN M. AND KATHRYN MERVINE FOWLER.

SERIES:

1. FUELS FROM PLANTS (BIOCONVERSION)
2. FUELS FROM WASTES (BIOCONVERSION)
3. WIND POWER
4. ELECTRICITY FROM THE SUN I (SOLAR PHOTOVOLTAIC ENERGY)
5. ELECTRICITY FROM THE SUN II
6. SOLAR SEA POWER (OCEAN THERMAL ENERGY CONVERSION)
7. SOLAR HEATING AND COOLING
8. GEOTHERMAL ENERGY
9. ENERGY CONSERVATION: HOME AND BUILDINGS
10. ENERGY CONSERVATION: INDUSTRY
11. ENERGY CONSERVATION: TRANSPORTATION
12. CONVENTIONAL REACTORS
13. BREEDER REACTORS
14. NUCLEAR FUSION
15. NEW FUELS FROM COAL
16. ENERGY STORAGE TECHNOLOGY
17. ALTERNATIVE ENERGY SOURCES: ENVIRONMENTAL IMPACTS
18. ALTERNATIVE ENERGY SOURCES: A GLOSSARY OF TERMS
19. ALTERNATIVE ENERGY SOURCES: A BIBLIOGRAPHY

COPIES CAN BE OBTAINED FROM:
DOE - TECHNICAL INFORMATION CENTER
P O BOX 62
OAKRIDGE, TN 37830

ENERGY FILMS INTERIM CATALOG 16MM, U.S. DEPARTMENT OF ENERGY WASHINGTON D.C. 1978.

THE ENERGY CHALLENGE, FEDERAL ENERGY ADMINISTRATION, WASHINGTON D.C.

COPIES CAN BE OBTAINED FROM:
THE ENERGY CHALLENGE
BOX 14306
OAKRIDGE, TN 45414

ACTIVITIES OF THE DEPARTMENT OF ENERGY IN ENERGY EDUCATION, U.S. DEPARTMENT OF ENERGY, WASHINGTON D.C. 1978.

COPIES CAN BE OBTAINED FROM:
NATIONAL TECHNICAL INFORMATION SERVICE (NTIS)
U.S. DEPARTMENT OF COMMERCE
5285 PORT ROYAL ROAD
SPRINGFIELD, VIRGINIA 22161

NSTA PUBLICATIONS, NATIONAL SCIENCE TEACHERS ASSOCIATION, WASHINGTON D.C. 1980.

AWARD WINNING ENERGY EDUCATION ACTIVITIES, ERHQ-0011 NATIONAL SCIENCE TEACHERS ASSOCIATION, WASHINGTON D.C. 1977.

YOUR ENERGY WORLD, U.S. DEPARTMENT OF ENERGY, WASHINGTON D.C. 1979.

SERIES:
1. ENERGY OVERVIEW
2. TRANSPORTATION: THE ENERGY EATER
3. ENERGY USE IN HOMES AND STORES
4. SCHOOLS CAN CONSERVE, TOO

COPIES CAN BE OBTAINED FROM:
DEPARTMENT OF ENERGY
TECHNICAL INFORMATION CENTER
P O BOX 62
OAK RIDGE, TN 37830

SCIENCE ACTIVITIES IN ENERGY, OAK RIDGE ASSOCIATED UNIVERSITIES UNDER CONTRACT FROM U.S. DEPARTMENT OF ENERGY, WASHINGTON D.C. 1979.

SERIES:
1. CONSERVATION
2. WIND ENERGY
3. CHEMICAL ENERGY
4. ELECTRICAL ENERGY
5. SOLAR ENERGY
6. SOLAR ENERGY II

COPIES CAN BE OBTAINED FROM:
U.S. DEPARTMENT OF ENERGY
TECHNICAL INFORMATION CENTER
P O BOX 62
OAK RIDGE, TN 37830

INTERDISCIPLINARY STUDENT/TEACHER MATERIALS IN ENERGY, THE ENVIRONMENT, AND THE ECONOMY, NATIONAL SCIENCE TEACHERS ASSOCIATION, 1979.

SERIES:
1. HOW A BILL BECOMES A LAW TO CONSERVE ENERGY, OCT. 1977
2. ENERGY, ENGINES, AND THE INDUSTRIAL REVOLUTION, OCT. 1977
3. NETWORKS: HOW ENERGY LINKS PEOPLE, GOODS AND SERVICES, FEB. 1978.
4. AGRICULTURE, ENERGY AND SOCIETY, AUGUST 1979.
5. COMMUNITY WORKERS AND THE ENERGY THEY USE, OCT. 1977
6. ENERGY IN THE GLOBAL MARKETPLACE, NOV. 1978.
7. MATHEMATICS IN ENERGY, NOV. 1978.
8. BRING ENERGY TO THE PEOPLE: WASHINGTON, D.C. AND GHANA, FEB. 1979.
9. WESTERN COAL: BOOM OR BUST? JUNE 1979.
10. TRANSPORTATION AND THE CITY, OCT. 1977.
11. TWO ENERGY GULFS, MARCH 1979.
12. U.S. ENERGY POLICY - WHICH DIRECTION? FEB. 1979.
13. ENERGY AND TRANSPORTATION, MARCH 1979.

COPIES CAN BE OBTAINED FROM:
U.S. DEPARTMENT OF ENERGY
TECHNICAL INFORMATION CENTER
P O BOX 62
OAK RIDGE, TN 37830

POWER: MECHANICS OF ENERGY CONTROL, RALPH C. ROHN, ANGUS J. MACDONALD, MCKNIGHT & MCKNIGHT PUBLISHING CO., BLOOMINGTON, ILLINOIS, 1970.

POWER: PRIME MOVER OF TECHNOLOGY, JOSEPH W. DUFFY, MCKNIGHT & MCKNIGHT PUBLISHING CO., BLOOMINGTON, ILLINOIS, 1964.

MODERN POWER MECHANICS, GRANNIS, GARY E., BOBBS-MERRILL EDUCATIONAL PUBLISHING, INDIANAPOLIS, IND, 1979.

EXPLORING POWER TECHNOLOGY - BASIC FUNDAMENTALS, WALKER, JOHN R., THE GOODHEART-WILLCOX COMPANY, INC. PUBLISHERS, SOUTH HOLLAND, ILLINOIS, 1976.

SMALL GAS ENGINES, ROTH, ALFRED C., THE GOODHEART-WILLCOX COMPANY INC. PUBLISHERS, SOUTH HOLLAND, ILLINOIS, 1978.

INTRODUCTION TO POWER SYSTEMS, ALAN SUESS, WILLIAM DUGGER, DALE PATRICK, JAMES ZIEGLER, GLENCOE PUBLISHING CO., INC., ENCINO, CAL. - COLLIER MACMILLAM PUBLISHERS, LINDON, 1976.

POWER TECHNOLOGY, GEORGE E. STEPHENSON, DELMAR PUBLISHERS, INC., ALBANY, NEW YORK 12205., 1968.

THE ENERGY EDUCATION BIBLIOGRAPHY: AN ANNOTATED BIBLIOGRAPHY OF KEY RESOURCES FOR ENERGY AND CONSERVATION EDUCATION., SHARON SCHERNER, JOHN JONES, ED DALTON, PREPARED BY ENERGY AND MAN'S ENVIRONMENT, 1978, 0224 S.W. HAMILTON, PORTLAND, OR 97201.

THE ENERGY AND CONSERVATION EDUCATION GLOSSARY: ED DALTON, D.ED., ANITA JONES, JOHN JONES, D.ED., SHARON SCHERNER, JON THOMPSON, PREPARED BY ENERGY AND MAN'S ENVIRONMENT, 0024 S.W. HAMILTON, PORTLAND, OR 97201.

THE ENERGY FILMS INDEX: AN EDUCATOR'S GUIDE TO CURRENT ENERGY FILMS, SHARON SCHERNER, JOHN JONES, ED DALTON, NOEL MCINNIS, PREPARED BY ENERGY AND MAN'S ENVIRONMENT, 1978, 0224 S.W. HAMILTON, PORTLAND, OR 97201.

POPULAR SCIENCE MAGAZINE.

SCIENTIFIC AMERICAN.

POPULAR MECHANICS.

ENERGY/POWER JOURNAL, PUBLISHED BY THE NATIONAL COUNCIL ON ENERGY AND POWER, P.O. BOX 618, CONCORD, MA 01742.

APPENDIX B

LIST OF MATERIAL & EQUIPMENT SUPPLIERS

APPENDIX B

LIST OF MATERIAL & EQUIPMENT SUPPLIERS:

1. ALLIED ELECTRONICS
   AE DIVISION, INC.
   401 E. 8TH STREET
   FORT WORTH, TEXAS 76102

2. BRODHEAD-GARRETT
   4560 EAST 71ST STREET
   CLEVELAND, OHIO 44105

3. EDMUND SCIENTIFIC
   101 E. GLOUCESTER PIKE
   BARRINGTON, NEW JERSEY 08007

4. ESTES INDUSTRIES
   PENROSE, COLORADO
   81240

5. HERBACK & RADEMAN, INC.
   401 EAST ERIE AVENUE
   PHILADELPHIA, PA 19134

6. INDUSTRIAL ARTS SUPPLY CO.
   5724 WEST 36TH STREET
   MINNEAPOLIS, MINNESOTA 55416

7. MARKSON
   MARKSON SCIENCE, INC.
   BOX 767
   DEL MAR, CA 92014

8. SATTERLEE CO.
   924 SOUTH 19TH AVENUE
   MINNEAPOLIS, MINNESOTA 55404

9. VALIANT
   195 BONHOMME STREET
   HACKENSACK, NEW JERSEY 07602

10. LOCAL HARDWARE STORES

11. LOCAL RADIO SCHACK STORES

12. MEGATECH CORPORATION
    29 COOK ST.
    BILLERICA, MASSACHUSETTS 01866

13. CENTRAL SCIENTIFIC CO
    11222 MELROSE AVENUE
    FRANKLIN PARK, ILL. 60131

APPENDIX C

PREFIXES AND ENGLISH/METRIC CONVERSIONS

UNIT # APPEN.C TOPIC METRIC PREFIXES

VISUAL #

TERA	10^{12}	= 1,000,000,000,000	TRILLION
GIGA	10^{9}	= 1,000,000,000	BILLION
MEGA	10^{6}	= 1,000,000	MILLION
KILO	10^{3}	= 1,000	THOUSAND
HECTO	10^{2}	= 100	HUNDRED
DEKA	10^{1}	= 10	TEN
UNIT	10^{0}	= 1	UNIT
DECI	10^{-1}	= .1	TENTH
CENTI	10^{-2}	= .01	HUNDREDTH
MILLI	10^{-3}	= .001	THOUSANDTH
MICRO	10^{-6}	= .000 001	MILLIONTH
NANO	10^{-9}	= .000 000 001	BILLIONTH
MICRO-MICRO OR PICO	10^{-12}	= .000 000 000 001	TRILLIONTH
FEMTO	10^{-15}	= .000 000 000 000 001	QUADRILLIONTH

VISUAL #

VOLUME

1 CUBIC CENTIMETER (CM^3 OR CC) =

1 CM^3
6.102×10^{-2} $IN.^3$
0.001 LITER
2.642×10^{-4} GAL
3.531×10^{-5} FT^3

1 GALLON (GAL) =

3785 CM^3
231 $IN.^3$
3.785 LITERS
1 GAL
0.1337 FT^3
3.785×10^{-3} M^3

1 CUBIC INCH ($IN.^3$) =

16.39 CM^3
1 $IN.^3$
1.639×10^{-2} LITER
4.329×10^{-3} GAL
5.787×10^{-4} FT^3

1 CUBIC FOOT (FT^3) =

2.832×10^4 CM^3
1728 $IN.^3$
28.32 LITERS
7.481 GAL
1 FT^3
2.832×10^{-2} M^3

1 LITER (l) =

1000 CM^3
61.02 IN^3
1 LITER
0.2642 GAL
3.531×10^{-2} FT^3

1 CUBIC METER (M^3) =

10^6 CM^3
6.102×10^4 $IN.^3$
1000 LITERS
264.2 GAL
35.31 FT^3

VISUAL #

TEMPERATURE

TEMPERATURE INTERVALS

$1^{o}C$ (CELSIUS OR CENTIGRADE) = 1^{o} K (KELVIN OR ABSOLUTE)

$= 1.8^{o}F$ (FAHRENHEIT)

$1^{o}F = 5/9\ ^{o}K = 5/9\ ^{o}C.$

CORRESPONDENCE BETWEEN TEMPERATURE SCALES

ON THE VARIOUS SCALES, THE NORMAL FREEZING POINT OF WATER IS: $32^{o}F = 0^{o}C = 273.15^{o}K$

CONVERSIONS BETWEEN TEMPERATURE SCALES

$T\ (^{o}F) = 32 + 1.8 \times T\ (^{o}C)$

$T\ (^{o}C) = 5/9 \times T(^{o}F) - 32$

$T\ (^{o}K) = 273.15 + T\ (^{o}C)$

	^{o}C	^{o}F	^{o}K
ABSOLUTE ZERO	-273.15	-459.67	0
NORMAL FREEZING POINT OF WATER	0	32	273.15
NORMAL BOILING POINT OF WATER	100	212	373.15

VISUAL #

ENERGY

1 JOULE (J) =

0.239 CAL

9.485×10^{-4} BTU

2.39×10^{-4} KCAL

2.778×10^{-7} KWH

1 CALORIE (CAL) =

4.184 J

3.968×10^{-3} BTU

0.001 KCAL

$1.162 \text{ c } 10^{-6}$ KWH

1 BRITISH THERMAL UNIT (BTU)=

1054 J

252 CAL

1 BTU

0.252 KCAL

2.929×10^{-4} KWH

1 KILOCALORIE (KCAL OR CAL) =

4184 J

1000 CAL

3.968 BTU

1 KCAL

1.162×10^{-3} KWH

1 KILOWATT-HOUR (KWH) =

3.6×10^{6} J

8.604×10^{5} CAL

3413 BTU

860.4 KCAL

1 KWH

VISUAL #

POWER

1 WATT (W) =

81.95 BTU/DAY

8.766 KWH/YR

0.001 KW

1 KILOWAT (KW) =

8.195×10^4 BTU/DAY

8766 KWH/YR

1000 W

1 HORSEPOWER (HP) = 746 W.

APPENDIX D

EQUIPMENT CONSTRUCTION NOTES

NOTES, EQUIPMENT CONSTRUCTION

STUDENT POWER TRAINER

MATERIALS REQUIRED:

- 3-10 SPEED BIKES
- 1 BIKE SPEEDOMETER
- 1-15 KG LAB SCALE (30 LB.)
- 30 FEET - 1 INCH ANGLE
- 2 FEET - ½ INCH DIAMETER ROD
- 2 FEET - ½ INCH DIAMETER PIPE
- 2 PIECES 1"x2"x3/4" PLYWOOD
- 1 AUTO ALTERNATOR
- 1-8"x8"x1/8" ALTERNATOR MOUNTING PLATE
- 1-3"x3" PIPE FOR FRICTION WHEEL
- 1 SPOOL NICROMO WIRE (HARDWARE STORE OR IASCO)
- 1-6V LANTERN BATTERY
- 1 PUSHBUTTON OR KNIFE SWITCH
- 1-2VOMs OR 1 AMMETER (10A) AND 1 VOLTMETER - 50V
- 3 PORCELAIN LAMP SOCKETS
- 3 METAL JUNCTION BOXES
- 3 METAL SWITCH BOXES
- 3 SINGLE POLE SWITCHES
- 3 COVER PLATES
- 3-100-300 WATT BULBS

MISCELLANEOUS:

WIRE, BOLTS, SCREWS, PAINT, ETC. ALL MATERIALS SHOULD BE AVAILABLE AT HARDWARE STORES. ONE EXCEPTION--LAB SCALE MAY BE OBTAINED FROM SCIENCE LAB OR SUPPLY HOUSE LISTED IN APPENDIX.

NOTES, EQUIPMENT CONSTRUCTION

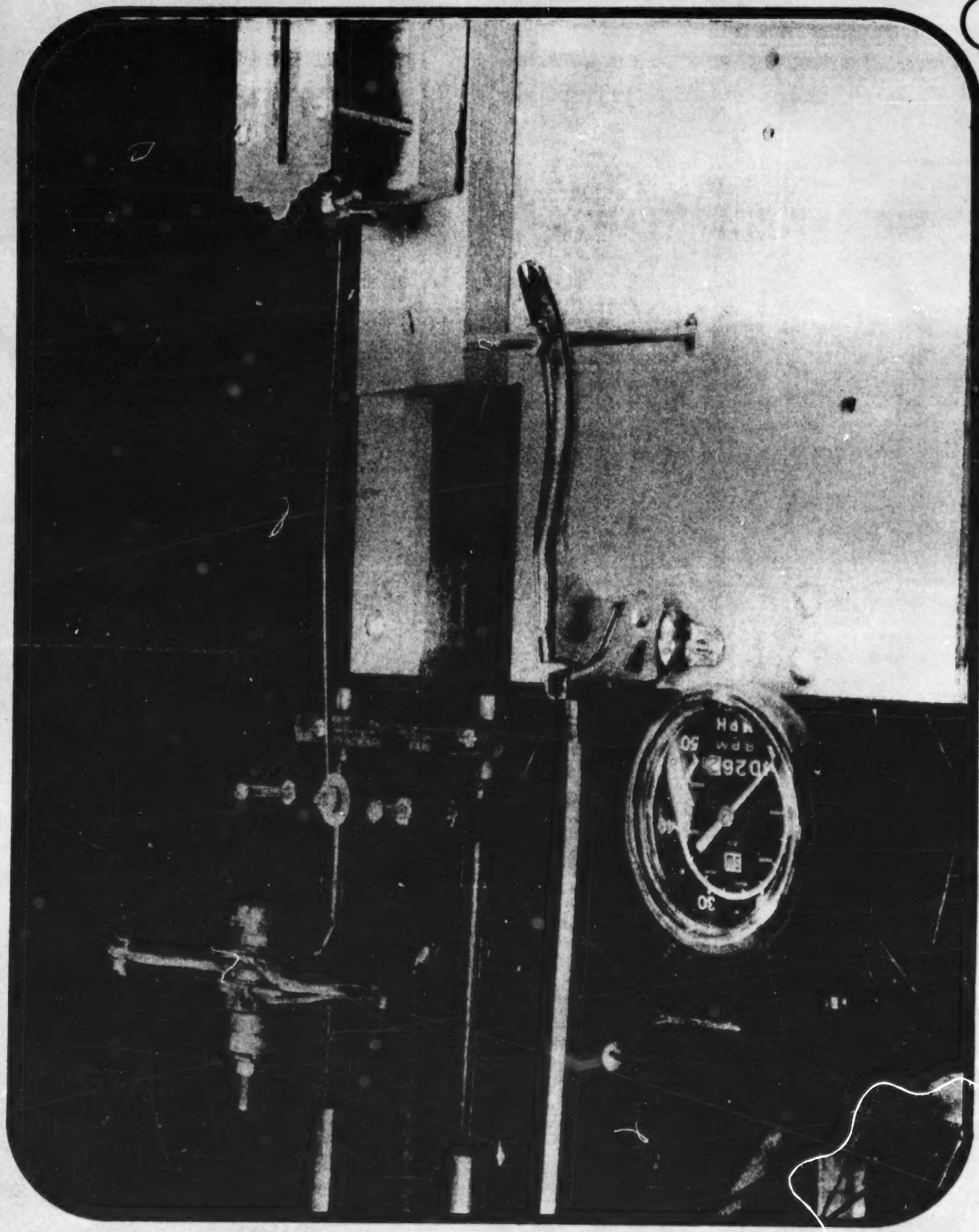
CONSTRUCTION:

CONSTRUCT THE SUPPORT BASE FIRST. IT SHOULD BE BOLTED TO BIKE IN AT LEAST THREE PLACES TO ASSURE A RIGID FRAME. NEXT, CONSTRUCT THE CALIPER SLIDE FRAME. SEE CLOSE-UP VIEW ON VISUAL. CALIPER MUST BE FREE TO SLIDE FORWARD AND BACK AND ALSO IN AND OUT TO GRIP WHEEL RIM. LENGTH OF TRAVEL OF SLIDE FRAME SHOULD BE AS SHORT AS POSSIBLE OR THE PADS WILL RUB ON TIRE. THE STRENGTH OF THE SPRING SCALE MUST BE AT LEAST 15 KG OR GREATER TO PREVENT EXCESSIVE SLIDE TRAVEL.

THE SPEEDOMETER DRIVE UNIT MAY HAVE TO BE MODIFIED AS MOST ARE DESIGNED TO FIT ON THE RIGHT OF THE FRONT HUB. TO AVOID THE DRIVE CHAIN, IT MUST BE MOUNTED ON THE LEFT REAR. AS A RESULT, IT WILL DRIVE THE SPEEDOMETER BACKWARDS UNLESS IT IS TURNED AROUND. SEE OTHER VISUAL FOR ALTERNATOR MOUNTING AND DRIVE. SEE THE STUDENT ACTIVITY OR VISUAL IN FIRST UNIT FOR WIRING SCHEMATIC.

UNIT # APPENDIX **TOPIC** PHOTO-CLOSEUP OF SCALE, CONTROL AND SPEEDOMETER.

VISUAL #



UNIT # APPENDIX TOPIC PHOTO-SETUP FOR ELECTRICAL POWER

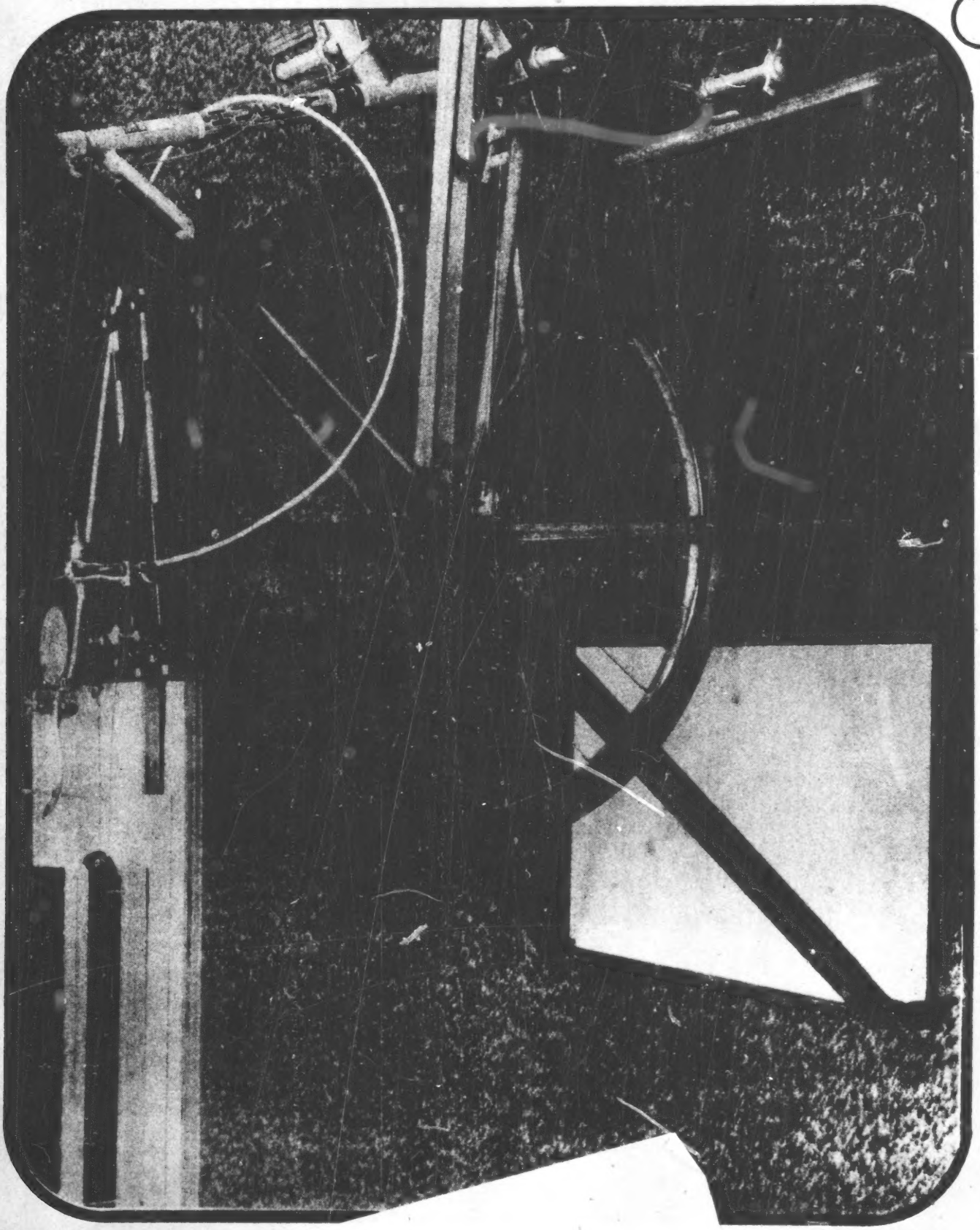
VISUAL # 213

UNIT # APPENDIX TOPIC CLOSEUP ALTERNATOR ASSEMBLY

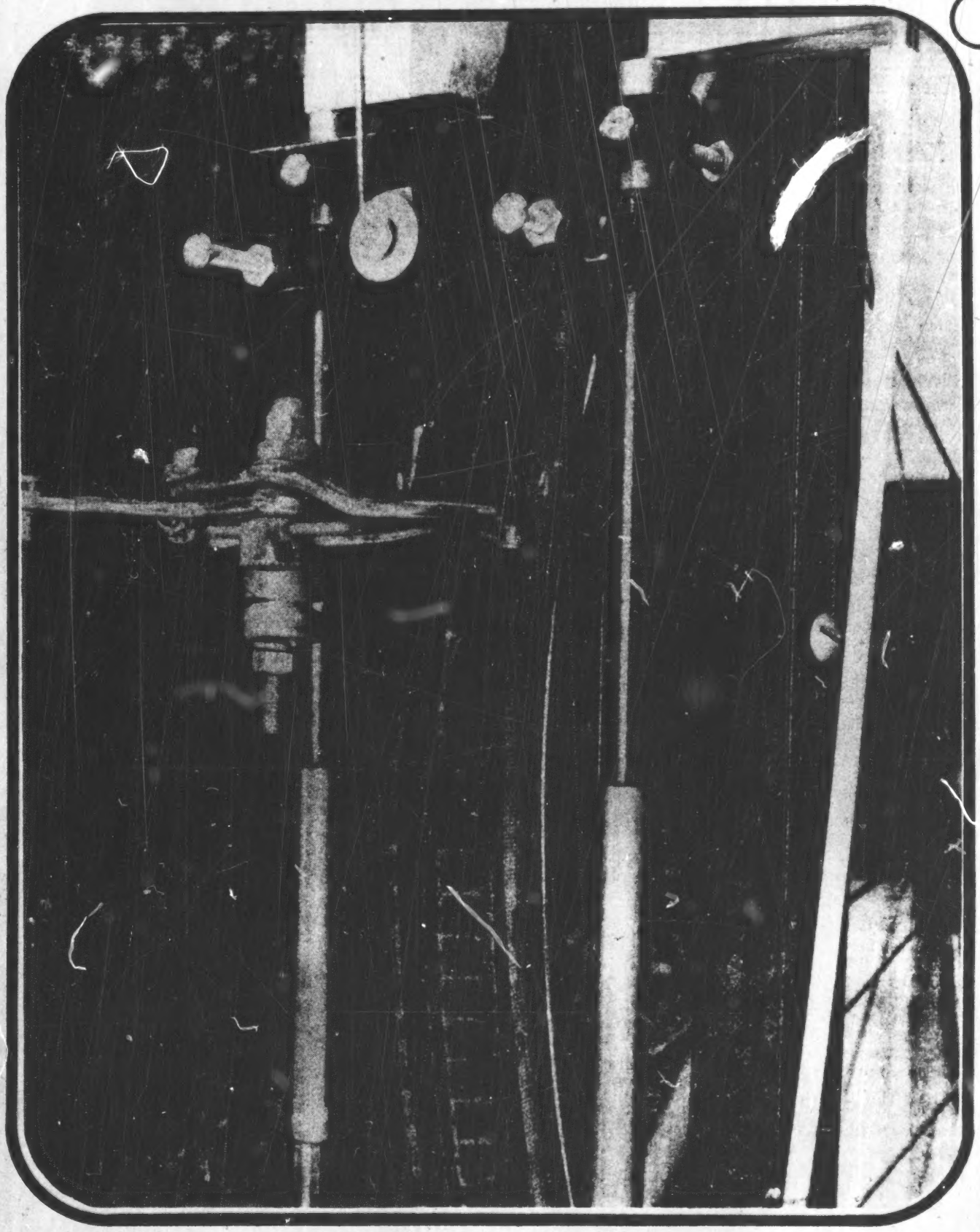
VISUAL # 245

UNIT # APPENDIX **TOPIC** STUDENT POWER DEMONSTRATOR PHOTO-SETUP FOR MECHANICAL POWER

VISUAL # 21



UNIT # APPENDIX TOPIC PHOTO-CLOSEUP SLIDE-BRAKE CALIPER



VISUAL # 219

218